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NUMBER 4

APRIL
1934

Published Monthly

FOR THE ADVANCEMENT OF THE SCIENCE AND ART OF WELDING

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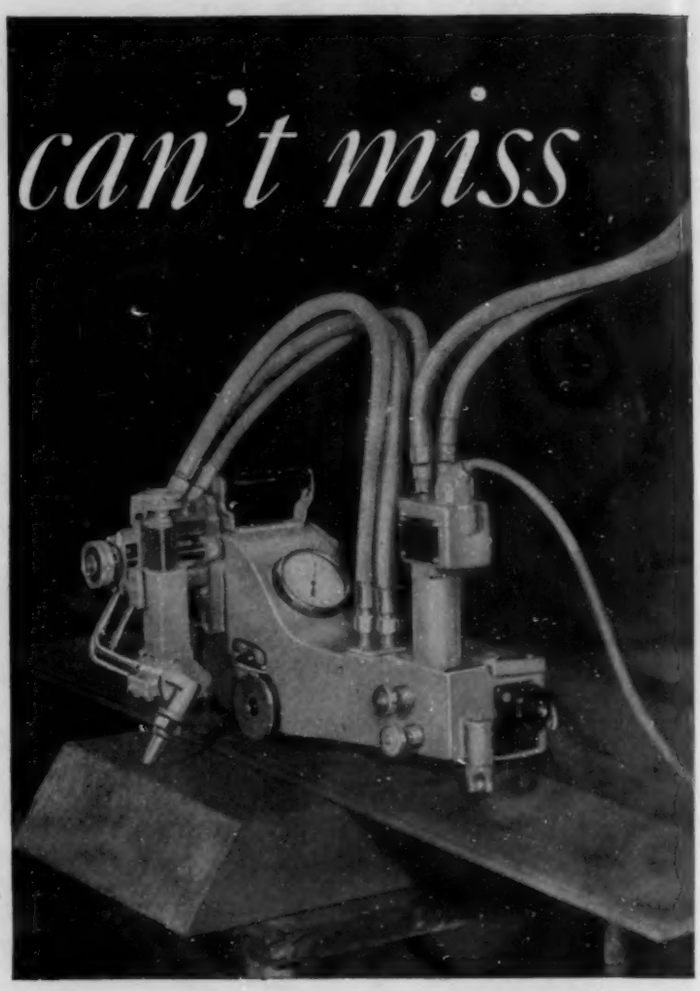

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APRIL
1934

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Editor

AMERICAN WELDING SOCIETY

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SOCIETY AND RELATED ACTIVITIES

New Members—March 1934

Class "B"

W. B. Chapman—E. M. F. Electric Co. Pty. Ltd., 1005 Rathdown St., North Carlton, Melbourne, Australia. Proposed by W. Spraragen.

James L. Edwards—H. G. Balcom, 10 E. 47th St., N. Y. C. Proposed by Milton Male.

G. O. Hoglund—Aluminum Co. of America, New Kensington, Pa. Proposed by F. M. Bernard.

J. P. Jackson—Athro Co., The Hayes Lye, Stourbridge, Worcestershire.

H. G. Marsh—Carnegie Steel Company, Pittsburgh, Pa. Proposed by F. M. Bernard.

Class "C"

H. N. Boetcher—Consolidated Gas Electric Light & Power Co., Baltimore, Md. Proposed by W. Spraragen.

J. P. Ganguisch—Pittsburgh Tube Co., Pittsburgh, Pa. Proposed by Membership Committee.

Gordon G. Goodwin, Tropical Oil Co., Colombia, S. A.

LaMotte Grover, State Highway Commission of Kansas, Topeka, Kansas. Proposed by Membership Committee.

Ira T. Hook—The American Brass Co., Ansonia, Conn. Proposed by Membership Committee.

R. P. Kelley—The Timken Roller Bearing Co., Canton, Ohio. Proposed by Membership Committee.

G. Elkins Knable—Carnegie Steel Co., Pittsburgh, Pa. Proposed by F. T. Liewellyn.

Jack Largent—MOP Lines, Houston, Texas. Proposed by Membership Committee.

A. Lucas—A. Lucas & Sons, Peoria, Ill. Proposed by Membership Committee.

H. E. May—Illinois Central Railroad, Chicago, Illinois. Proposed by Membership Committee.

S. M. McManus—Muskogee Iron Works, Muskogee, Okla. Proposed by Membership Committee.

D. A. Mower—Mechanic Arts High School, Boston, Mass. Proposed by L. F. Jackson.

A. H. Pendlebury—Worthington Pump & Machinery Corp., Harrison, N. J.

M. W. Posey—Lancaster Iron Works, Lancaster, Pa. Proposed by Membership Committee.

A. G. Sprague—Sprague Service & Supply Co. 276–78 Davidson Ave., Perth Amboy, N. J. Proposed by S. C. Lum.

Richard W. Sternke—Lakeside Bridge & Steel Co., Milwaukee, Wis. Proposed by K. B. MacKenzie.

B. M. Walsh—Boston & Maine Railroad, Springfield, Mass. Proposed by H. N. Ewertz.

George W. Warner—Armco International Corp., Middletown, Ohio. Proposed by A. F. Davis.

L. K. Whitcomb—Carnegie Steel Co., Cleveland, Ohio. Proposed by A. F. Davis.

C. Delbridge—Air Reduction Sales Co., Upham Crs., Boston, Mass. Proposed by F. E. Rogers.

M. M. Weist—Air Reduction Sales Co., Chicago, Illinois. Proposed by F. E. Rogers.

C. M. Hendry—Air Reduction Sales Co., Cleveland, Ohio. Proposed by F. E. Rogers.

H. R. Salisbury—Air Reduction Sales Co., Philadelphia, Pa. Proposed by F. E. Rogers.

H. F. Henriques—Air Reduction Sales Co., Cleveland, Ohio. Proposed by F. E. Rogers.

C. H. Adams—Air Reduction Sales Co., Philadelphia, Pa. Proposed by F. E. Rogers.

J. J. Lincoln—Air Reduction Sales Co., Pittsburgh, Pa. Proposed by F. E. Rogers.

G. M. McBride—Air Reduction Sales Co., Seattle, Washington. Proposed by F. E. Rogers.

"Class D"

E. D. Anderson—The Lincoln Electric Co., Cleveland, Ohio. Proposed by A. F. Davis.

E. J. Drovillard—Chevrolet Motor Co., Detroit, Mich. Proposed by Wm. M. Hayes.

Howard J. Edelman—Nazareth Steel Fabricators, Nazareth, Pa. Proposed by Membership Committee.

N. R. Patterson—Patterson Steel Company, Tulsa, Oklahoma. Proposed by Membership Committee.

Building Officials' Conference

The Building Officials' Conference of America and the New England Building Officials' Conference will hold a joint convention in Boston, Massachusetts during the week starting April 23, 1934.

(*Continued on page 3*)

FIFTEENTH ANNUAL MEETING OF THE AMERICAN WELDING SOCIETY APRIL 26, 1934

Important Notice

Members and their guests are requested to register. All sessions start promptly as scheduled.

Thursday, April 26th

Morning

REGISTRATION

11:00 A.M. Business Session—Engineering Societies Building, 33 West 39th Street, New York, Room 3, 5th floor—President F. P. McKibben, presiding.

PROGRAM

Report on Society Activities by President McKibben.
Tellers' Report on Election of Officers.
Other Business—Discussion.

Afternoon

2:00 P.M. Meetings of American Bureau of Welding and Structural Steel Welding Committee, Engineering Societies Building, 33 West 39th Street, New York, Room 3, 5th floor.

AMERICAN BUREAU OF WELDING—C. A. Adams, Director, Presiding

PROGRAM

Reports of Committees.
Election of Officers.
Proposed new Research Work.

STRUCTURAL STEEL WELDING COMMITTEE,
L. S. Moisseiff, Chairman, Presiding

Proposed program of seat angles and beam connections will be presented by Professor Inge Lyse of Lehigh University and his assistant. The results of pilot tests in connection with this program will be presented with the aid of lantern slides.

Evening

6:30 P.M. Meeting Board of Directors—Hotel New Yorker, Parlor E, 8th Ave. and 34th Street, New York. Dinner (subscription price $2.00) followed by meeting—F. P. McKibben, presiding.

PROGRAM

Review of Society activities.
Unfinished Business.
Introduction of new President.
Appointment of Officers and Committees.
Plans for coming year.

(*Continued from page 2*)

This meeting will be the largest meeting of building officials ever held, both in the number in attendance and in the territory represented by them.

At this meeting topics of vital interest to every one connected with the building industry will be expounded and discussed. Some of the topics tentatively arranged are as follows: "The P.W.A. and Its Effects on the Building Industry," "The C.W.A. and Its Effects on the Building Industry," "Proper Building Construction," "Duties of Building Officials and Importance of Building Departments," "The Housing Problem in America," "A Résumé of Building Conditions and Prices during the Past 3 Years." These topics will be expounded by leading authorities. There will also be discussion on "New Materials, New Design and New Methods of Building Construction."

Arc Welding Construction

Westinghouse Electric & Manufacturing Company has issued an Arc Welding Data Bulletin No. 18 which describes the benefits of arc-welded constructions and gives numerous examples.

(*Continued on page 33*)

SECTION ACTIVITIES

BOSTON

About 350 members and guests attended the March 16th meeting of the Boston Section, held at the plant of the Austin-Hastings Company, Cambridge. The program consisted of motion pictures on machine tool operations, demonstrations of the Raytheon arc welding machine and demonstrations of metallizing. Refreshments were served at the conclusion of the meeting.

CHICAGO

The March meeting of the Chicago Section was held on March 23rd at the Bismarck Hotel, Chicago. The speakers were: Mr. E. L. Quinn of the American Manganese Steel Company, who spoke on the subject of "Successful Manganese Steel Welding," and Mr. Jules Muller of the Hollup Corporation who spoke on "Selection of Correct Electrodes for Different Welding Jobs."

CLEVELAND

The regular monthly meeting of the Cleveland Section was held on March 14th at the Cleveland Engineering Society. The speaker of the evening was Mr. A. M. Candy of the Westinghouse Electric & Manufacturing Company, whose subject was "Welded Mechanical Equipment Built by Westinghouse." Mr. Candy spoke on the welded equipment built by Westinghouse and particularly of the welded thirty-foot diameter intake valves for the Boulder Dam. The address was illustrated with lantern slides of welding equipment fabricated in the Westinghouse plant.

DETROIT

A meeting of the nominating committee of the Detroit Section was held on Monday, March 5th. The following officers and members of the Executive Committee for 1934–1935 were elected:

Chairman, R. P. Bailey, General Electric Company

Vice-Chairman, W. M. Hayes, Air Reduction Company

Secretary-Treasurer, Jos. Matte, Jr., Albert Kahn, Inc.

Member of Executive Committee, W. H. Simmons, Welding Sales & Engrg. Co. and P. W. Fassler, Fisher Body Corp.

LOS ANGELES

The regular meeting of the Los Angeles Section was held at Cole's Cafeteria in Huntington Park, Thursday, February 15th.

Mr. W. T. Wheeling, public accountant, spoke on "Modern Accounting for Modern Welding Shops." Mr. Wheeling gave a very interesting talk on job shop welding costs and went thoroughly into different items of costs and overhead. His comments on figuring portable welding costs and depreciation on this equipment were very interesting.

Mr. Burt, in charge of engineering and manufacturing at Baker Oil Tools, Inc., was the next speaker. His subject was "Welding Costs and Overhead in Oil Field Equipment Shops." Mr. Burt's paper was very thorough and dealt with the many variables that enter into welding costs.

NEW YORK

A lecture on Recent Developments in the Welding and Cutting of Metals will be presented at the Joint Meeting of the New York Chapter, American Society for Metals and New York Section, AMERICAN WELDING SOCIETY, on Monday, April 23rd at 8:00 P.M., Room 502, Engineering Societies Building, 33 West 39th Street. Mr. James Lee, Managing Editor of Chemical and Metallurgical Engineering, will be the speaker.

The final meeting of the 1933–1934 season will be held on May 8th at 8:00 P.M. in Room 502, Engineering Societies Building. The meeting will be devoted to the subject of reconstruction and repair of steel structures by welding.

PHILADELPHIA

At the March meeting held on the 19th a talk on "Reclamation in the Automotive Field" was presented by Mr. S. C. Clark, Technical Publicity Department, Linde Air Products Company.

The following officers were elected:

Chairman, A. G. Desch, Oxweld Acetylene Company.

Vice-Chairman, W. F. Carson, Carson & Carson.

Treasurer, R. D. Thomas, R. D. Thomas & Company.

Secretary, H. E. Hopkins, R. D. Thomas & Company.

Section Member on National Board of Directors, R. D. Thomas.

At the April (Annual) Meeting a paper by Dr. T. Holland Nelson, Consulting Metallurgist and Engineer, will be presented on "Welding of Stainless Steel."

There will be no May meeting this year.

PITTSBURGH

A full house attended the March 21st meeting of the Pittsburgh Section to hear Mr. W. D. Halsey of the Boiler Division of the Hartford Steam Boiler Inspection and Insurance Company, discuss the "Attitude of Insurance Companies toward Welded Pressure Vessels."

By the interest manifested by those present, drawn from practically all of the industrial plants in this district, insurance companies, engineers and others, it was evident that the subject was of more than ordinary importance.

The detailed manner in which Mr. Halsey presented his discussion, using slides to illustrate his talk, clearly demonstrated the position of insurance companies with relation to the art of welding.

Following his talk Mr. Halsey discussed informally many points brought up by those present and also showed samples of welds he had brought with him.

SAN FRANCISCO

The San Francisco Section held its March meeting on the 23rd at the Athens Club at Oakland. Mr. C. S. Conrad, Manager of Sales, Stainless Products Department, Columbia Steel Company, gave a very interesting talk on "A Preview of the Modern Applications of High Strength Steel Alloys."

Dr. Robert J. Wiseman, Chief Engineer of The Okonite Company at Passaic, N. J., spoke on "The Old and New Insulations—with Particular Reference to Electric Arc Welding Cable."

EMPLOYMENT SERVICE BULLETIN

SERVICES AVAILABLE

A-146. Welding Engineer, college graduate, 18 years' experience in steel fabrication, last 6 years devoted exclusively to the application of electric welding; competent to handle any branch of the program of applying electric welding to the design, fabrication and erection of structural steel and ornamental iron.

V-56. Welding Engineer wanted. Must be A1, foreign experience desirable. State age and experience. Salary open—real opportunity.

Resistance Welding of Aluminum and Its Alloys

By D. I. BOHN

✦Paper presented at the Nov. 22, 1933 Meeting of the New York Section, A. W. S., by D. I. Bohn of the Aluminum Company of America.

MR. CHURCHILL has extolled the virtues of the aluminum alloys to such an extent that possibly you have gained the impression that they have excellent characteristics from a resistance welding standpoint. Unfortunately, this is not the case, and a great many of the characteristics which have made them so valuable and useful militate against the ease of welding, which characterizes some other materials.

The aluminum alloys all have a relatively high electrical conductivity, high thermal conductivity and, in addition, must be actually molten to produce a weld.

The effect of these characteristics on the technique employed for successful resistance welding will be somewhat evident. The high electrical conductivity demands an amperage several times as great as that required for steel, and the high thermal conductivity demands that an extremely short time of power application be used in order to avoid general heating and collapse when melting is reached. This again indicates a still higher current than would be necessary if a longer time could be used. Also, the fact that the metal must be actually molten to produce a weld requires that the melting be extremely localized in the case of spot or seam welds and that the outside surfaces of the sheets contacting the electrodes be practically cold and, therefore, mechanically unaffected.

This does not mean, however, that the same excellent results, which are obtainable with steel and other commonly used materials, are impossible to obtain with aluminum alloys, nor are the methods impractical in any way.

Those of you who have spot welded aluminum on commercial machines will probably realize that often at

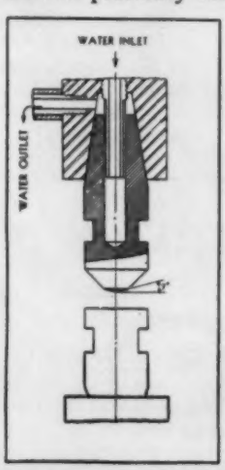


Fig. 1—Recommended Design of Electrodes. One of Them Is Cone Shaped and the Other Flat

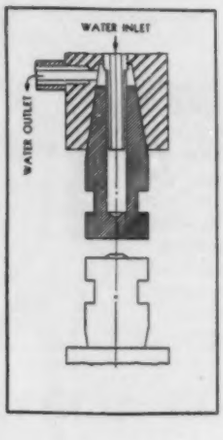


Fig. 2—A Type of Electrode Which Gives Good Results Without Synchronous Control

the best the results are not very satisfactory. In the case of the common alloys and when the sheets are not too thin, reasonably good spot welding can be done with any existing automatic spot welder, provided it is of sufficient electrical capacity. There is no known way to make up for lack of sufficient electrical capacity, and a great many of the unsatisfactory results which have been obtained are a direct result of trying to do a job with 10,000 or 15,000 amps., which should require 25,000 amps.

Those of you who have existing equipment, with very slight modifications, can do a reasonably good job on the common alloys if sufficient electrical capacity is present. In general, a 60 kv-a., 18-in. throat spot welder will handle two sheets each of 0.050 to 0.060 in. A minor change to permit such work may consist of eliminating the undesirable characteristics of the A.C. contactor handling the primary current. The usual practice is to operate the coil of this contactor from a cam-operated pilot switch, which is part of the machine motor drive.

Since the operation of this cam is entirely non-synchronous in practically all cases, it is apparent that some variation in time delay of closing would be expected up to approximately one-half cycle. This error, which is entirely inappreciable when welding steel, becomes of considerable moment with aluminum as the time of power duration must be cut down to a low value, usually a few cycles.

This is not the greatest error which the characteristics of the A.C. contactor possess. Variations in opening time, as checked oscillographically, show variations of as much as two or more cycles in successive spots. This variable delay is a function of the point on the A.C. wave when the contactor coil is de-energized, and the actual large variation is caused by the effect of the shading coil.

If the coil circuit is opened when the flux is at a maximum or at a large value, the collapse of the flux will induce a heavy current in the shading coil and cause the contactor to hold in for a cycle or two. If this circuit is opened, however, when the magnetic flux is at or near zero, a quick drop-out will be obtained.

All that is required to minimize this condition is to remove the shading coil and operate the contactor from a D.C. circuit, preferably selecting a new coil, which will permit a series resistor to be used in the circuit and increase the speed of the pick-up.

With such a set-up these undesirable time variables are not eliminated, but are merely minimized; but conditions are improved sufficiently to permit good, satisfactory commercial work on the common alloys up to the limit of the machine's capacity.

However, we are primarily interested in not merely a fair job but a first-class one, so it is desirable to not merely minimize but completely eliminate all the variables which we have under our control.

Since the problem of accurate power timing is one of the most important, the elimination of any variables in this direction constitutes the first important step. Absolutely precise, synchronous timing is now available in the form of the electronic equipment built for welding purposes. This equipment will permit successive shots of synchronously timed power.

It is, of course, important that successive spot welds be made with the same welding current. This is not a serious or difficult matter as, if line regulation is reasonably good—only varying a few per cent at different periods of the day—a given power setting will remain substantially constant. If for any reason a line voltmeter indicates that some variation is being obtained, a small automatic induction voltage regulator should be used which will compensate for any serious variations.

The basis of successful spot welds in aluminum alloys is the establishing of an extremely high thermal gradient from the point of weld to the outside of the sheet contacting the electrode, and in this connection the surface resistance between the sheets plays an important part. The greatest proportion of the heat, which is present to cause melting, is obtained from the flow of current through these contacting sheet surfaces. Here is a possible variable, therefore, which is somewhat more difficult to control than the obvious ones, such as timing, current or pressure.

With a given lot of material this surface resistance is a fairly constant figure, but suffers from some variation even on different parts of the same sheet. This variation is a much greater percentage when the electrode pressure is low than when it is high, and for this reason the use of the highest practicable pressure is recommended. The permissible range of pressures to do a certain job is quite large and not at all critical, but once a given adjustment is made it must not be permitted to vary for successive spots. Any reliable means to apply the pressure is satisfactory, but for most purposes we prefer a pneumatic cylinder, gage and pressure reducer. A solenoid valve, properly sequenced with the control scheme, automatically takes care of the application and removal of pressure. Also, by using a pneumatic cylinder rather than the conventional cam construction, the stroke may be made anything desired, up to the maximum for which the machine is designed.

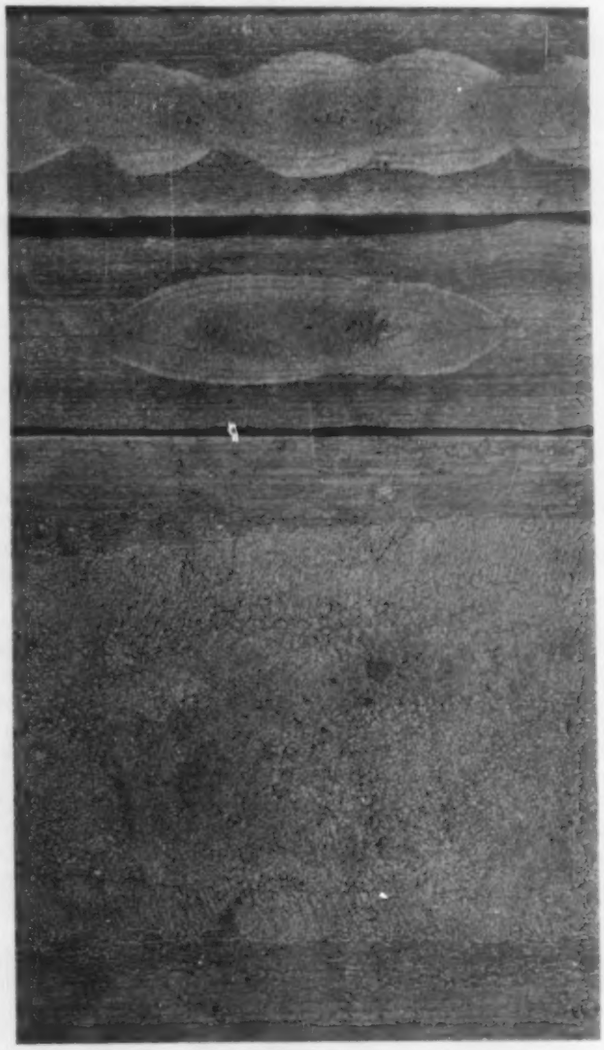
Low inertia of the moving parts is a very desirable attribute for spot welding aluminum, and the design should use every means possible to cut down the weight of the upper electrode assembly. We have done this by using a design in which an aluminum alloy operates both mechanically and electrically by providing the desired strength of the upper arm and carrying the current as well. When very thin sheets are being spot welded, the adjustable stroke is advantageous as it permits the electrode opening to be just large enough to accommodate the work, and in this way harmful hammer blow is avoided.

The question of secondary voltage is often asked with respect to the welding of aluminum alloys. It must be emphasized that secondary voltage, as such, has nothing whatsoever to do with the job as the current flowing to produce the weld is entirely responsible for the result. In the design of the machine, however, the most suitable secondary voltage to be selected becomes of considerable importance as it is responsible for forcing the required current through the secondary circuit.

The current that flows in a spot welder made for aluminum is, practically speaking, independent of the work which is being done and is almost entirely governed by the reactances of the various parts of the secondary circuit. The resistances of the circuit, or of the work, constitute in themselves such a small voltage drop that variations in them do not affect the amperes flowing but a fraction of one per cent. For this reason the design of a machine is purely an electrical problem involving the study of reactances in a heavy current circuit. The selection of the proper voltage to give the desired current indicates the kv-a. input, as the product of welding current and open circuit secondary volts is a direct measure of this kv-a.

The duty cycle for aluminum is so low that the problem of electrical design is primarily one of obtaining the desired current and not of designing to prevent overheating of the transformer and other heavy current carrying parts.

Fig. 3(a) (Upper) Fig. 3(b) (Center) Fig. 3(c) (Lower)



Figures 3a, 3b and 3c illustrate the structure of a typical strong alloy seam weld and are also typical of a spot weld. The unaffected surface metal and the cast molten bubble constituting the weld indicate the extremely steep thermal gradient, which is the basis of successful spot and seam welding. Figure 3a also shows the spaced pulsations of current as controlled by electronic means.

Fig. 3(a)—Longitudinal Section of a Seam Weld in 0.051-In. 53S-W Sheet. Original Magnification 25 Diam. Reproduction Reduced 2½ Times

Fig. 3(b)—Same Weld and Magnification Shown Transversely

Fig. 3(c)—Another Transverse Section of the Same Weld. Original Magnification 100 Diam. Reproduction Reduced 2½ Times

Water cooling must be employed for the electrodes as they constitute the neck of the bottle and it is usually employed for the transformer secondaries, although it is doubtful if an aluminum spot welder really requires the latter.

The consideration of the various frequencies is of some interest as the minimum gage of material which can be welded satisfactorily is a function of frequency. For instance, we employ one cycle (using a 60-cycle power supply) for welding 0.020-in. sheets. Although we have not made use of the higher frequency for welding thinner sheets, there is little doubt but what a 120-cycle power supply would be advisable to do a first-class job on 0.010-in. sheets.

Conversely, to weld very heavy materials there is some advantage in lower frequencies such as 15 to 25 cycles. Since the kv-a. of a given machine varies almost directly with the frequency, for extremely heavy work a 1000 kv-a. machine might be required if designed for 60 cycles; whereas 250 or 300 kv-a. is all that would be necessary if 15 cycles were employed. For the majority of work, however, 60 cycles seems to be a very good compromise, permitting perfect results in 0.020-in. sheet and not requiring an absurdly high kv-a. for material up to $^1/_8$ in.

Possibly mention should be made at this time of the expected results to be obtained in spot welding the various common and strong alloys when suitable and first-class equipment is provided. We have run several hundred spot weld tensile specimens to evaluate the consistency of the spot welds made with this type of equipment. It may be safely stated that, under these conditions and with good judgment used in making the initial set-up, the expected strength variation in spots will be between 90 and 110% of the average strength. This, I believe, compares very favorably with the results obtained with other materials and should serve as an indication that the spot welding of these alloys is just as practical and consistent in results as practically any other forms of fabrication.

The aluminum alloys may be divided, from a spot welding standpoint, into three groups—the common alloys, the strong alloys and the Alclad alloys.

The common alloys are those whose properties are obtained entirely from the alloy and working, and not from any heat treatment. They require, in general, no surface preparation and, unless they have been permitted to become very dirty, they may be spot welded as received.

Some of the strong alloys receive their heat treatment by being heated in a nitrate bath to the proper quenching temperature, and then quenched in water. This operation provides a relatively high resistance oxide surface, as indicated in most cases by the grey color. It is fairly consistent in its resistance characteristics and is not harmful to the quality of the weld. It is advisable, and in some cases practically necessary, to remove the oxide surface by sandpapering, or the equivalent, on the outside sheet surfaces which contact the electrodes. If this is not done, the electrodes will be quickly alloyed with aluminum and require frequent cleaning. In some cases it is desirable, although not necessary, to remove the oxide from one of the inner surfaces, but in no case have we found it advantageous to remove the oxide from both inside surfaces. These latter remarks apply to practically all of the nitrate heat-treated alloys, such as 17ST, 24ST, 51ST, 53ST and several others less commonly known.

The Alclad materials usually consist of one of the strong alloys whose outside surface consists of a 5% thickness of practically pure aluminum. This pure aluminum surface provides electrolytic resistance to corrosion, making these alloys some of the most useful for aircraft and other work where the thicknesses are not great and corrosion becomes a factor.

These Alclad alloys require no surface preparation of any sort as the pure aluminum surface does not cause appreciable alloying with the electrodes.

Our work is very naturally far from complete with respect to the study of corrosion of spot welds in these various alloys. We have quite definite indications, however, that the spot welds in the Alclad materials are excellently protected and that corrosion is practically as negligible with them as it is with the material itself. This is what might be expected as the Alclad surface provides the same electrolytic protection as rivets which do not have an Alclad surface themselves, so that even if the spot weld should damage to some extent the Alclad surface, the area of exposed inner metal is protected electrolytically by its proximity.

Various types of electrode designs have been tried, and the most satisfactory one has a conical contacting surface. The cone is quite flat with an included angle of about 160 to 165°. This design provides an initial low area of contact, the area increasing rapidly as the electrode sinks into the surface of the metal. As the weld is completed, this reduces the current density and in itself provides quite a stabilizing action, tending to minimize effects of surface resistance variation or slight power changes.

With such an electrode design variations in power over quite a range merely affect the diameter of the resulting spot rather than the quality or soundness.

When desired, one of the electrodes may be left flat, the other one being as described, although for thick material, such as 0.100 in., or where three or four sheets are welded together, it is preferable to have both electrodes of this design.

Seam welding is a continuous and special form of spot welding, and practically all of the previous statements apply directly to it. The fact that successful spot welding of these alloys requires relatively short times of power application indicates that the same condition must exist for satisfactory seam welding, and experience demonstrates this to be so.

The machine employed is very similar to the spot welder, except that the electrodes consist of rollers, either one or both of these being mechanically driven at a constant speed. Power supply is controlled by electronic means to give any desired number of cycles "on" and "off." Experience has shown that the percentage of time when the power is on should be around 25%, or lower when possible. This value is a compromise between the maximum current available and the desired thermal conditions. If power is applied, let us say, for two cycles on and two off, the tendency will be for the molten bubble to approach the sheet surface too closely, with the possibility of excessive electrode pick-up from the high temperature aluminum adjacent to the electrode. If an adjustment is made to give, let us say, one cycle on and seven off, the thermal gradient will be very steep and the outside sheet surface will not become hot enough to alloy with the rollers. More power is required, of course, for this last setting than if one cycle on and three off were employed, so that, in general, the tendency should be to employ a setting which gives a lower percentage for the "power on" period. It goes without saying, of course, that these adjustments must be precise and the control of power synchronous in every way, which practically eliminates the use of the old-style mechanical interrupter.

The cycles employed are also dependent upon the desired speed to some extent. In order to make a gas-

or liquid-tight seam, the spots must well overlap each other and this spacing is a function of the "on plus off" cycles and the peripheral electrode speed.

No trouble whatsoever is experienced in making gas-tight seams in any of the alloys when the proper equipment is available. In most cases the gas-tight seams are only employed for a container or pressure vessel, and the use of common alloys is preferable as the ductility of the welds is much greater than with the strong alloys.

It is often thought that the field of seam welding includes only those jobs requiring a gas- or liquid-tight seam, but this is by no means the case. A great many mechanical applications which would normally be riveted or spot welded may be seam welded with a cycle setting to properly space the spots and simulate a spot welded or riveted joint. The operation is usually five or ten times as fast as spot welding, the results just the same and the cost materially decreased.

Butt welding of these alloys differs considerably from spot and seam welding, although the characteristics of the alloys again demand that a procedure be used which is considerably different than that employed for most other materials.

We have had no appreciable success with flash welding as practiced with steel, and the method employed is one of pure resistance welding—no disturbance or fireworks being present during the operation.

The fact that flash welding has not proved satisfactory limits the application of butt welding to sections which do not have a too great proportional difference in width and thickness; that is, it would be extremely difficult to satisfactorily butt weld two thin sheets to each other.

The general procedure for butt welding is to clamp the materials in suitable electrodes and apply the proper pressure, followed by the application of power. For this method definite time is not used, but instead a limit switch is arranged to cut off power when a pre-set travel has been reached.

This procedure sounds quite simple and this is the case for simple sections such as rounds, squares or oblongs of reasonable proportion.

Since the proper current distribution which is inherently present with any flash welding method is not available with this form of butt welding, it is necessary to obtain such current distribution by skilful electrode design. This is comparatively easy with the simple sections, but becomes increasingly difficult as more complicated sections, such as some of the architectural ones, are used.

The distance between the electrode faces, that is, the amount of unsupported material between the electrodes, is a compromise. From a current distribution standpoint the greater this distance the better, but as the complexity of a section increases it is necessary to support it quite close to the weld in order to avoid mechanical failure of the metal directly adjacent to the weld.

A general rule for simple sections is 2000 lb. and 30,000 amp. per sq. in. This is only very approximate as the shape of the section and the alloys employed will cause considerable variation in these figures.

The field of butt welding in the aluminum alloys is probably somewhat limited due to the metallurgical conditions which obtain. If a high strength alloy is used because it is necessary for the job, it is very probable that the reduction in strength throughout the entire butt-welded section would not permit its use. This does not apply, of course, to spot or seam welding, the strength of whose joints can be made to equal or exceed similar riveted joints.

The greatest application of butt welding will probably be in the architectural field where it seems to offer excellent possibilities for window frames and similar articles. The strength obtained is more than ample for this class of work, and it is expected that, as further development along these lines is made, cost and other advantages will dictate its widespread use.

As is the case with spot and seam welding, most applications will require the installation of specially designed equipment to provide the heavy necessary current and low inertia of moving parts necessary for aluminum sections.

Cost of Welding versus Cost of Fittings in Pipe-Lines

By **ALBERT UHLIG**

DURING a recent visit to Europe the writer helped prepare some interesting charts and obtained important facts pertaining to the economy of welding of gas, steam and water pipe-lines and other steel pipe constructions. The exhaustive studies and analysis of economical welding practices and their application in pipe systems has helped welding too, because of their vital importance in the building trade and a great many other industries.

An oxyacetylene welded joint not only gives the best possible density and strength, but it is just as advantageously applied in water and steam as well as in gas distributing systems for any given pressure. The advantage of welded pipe-lines consists mainly of its exceedingly low cost, its remarkable strength and neat appearance compared with the old method of screwed and fitted joints. In no other way are pipe-lines made so economical and perfect. To obtain a perfect joint the two or more pipes should be heated first to secure a good alignment. A fair aligned joint is desired to prevent the forming of small bubbles on the inside of the pipe, which are detrimental to the unresisted flow in the line. Any welder with some experience knows that and also knows how to prevent such "tumors."

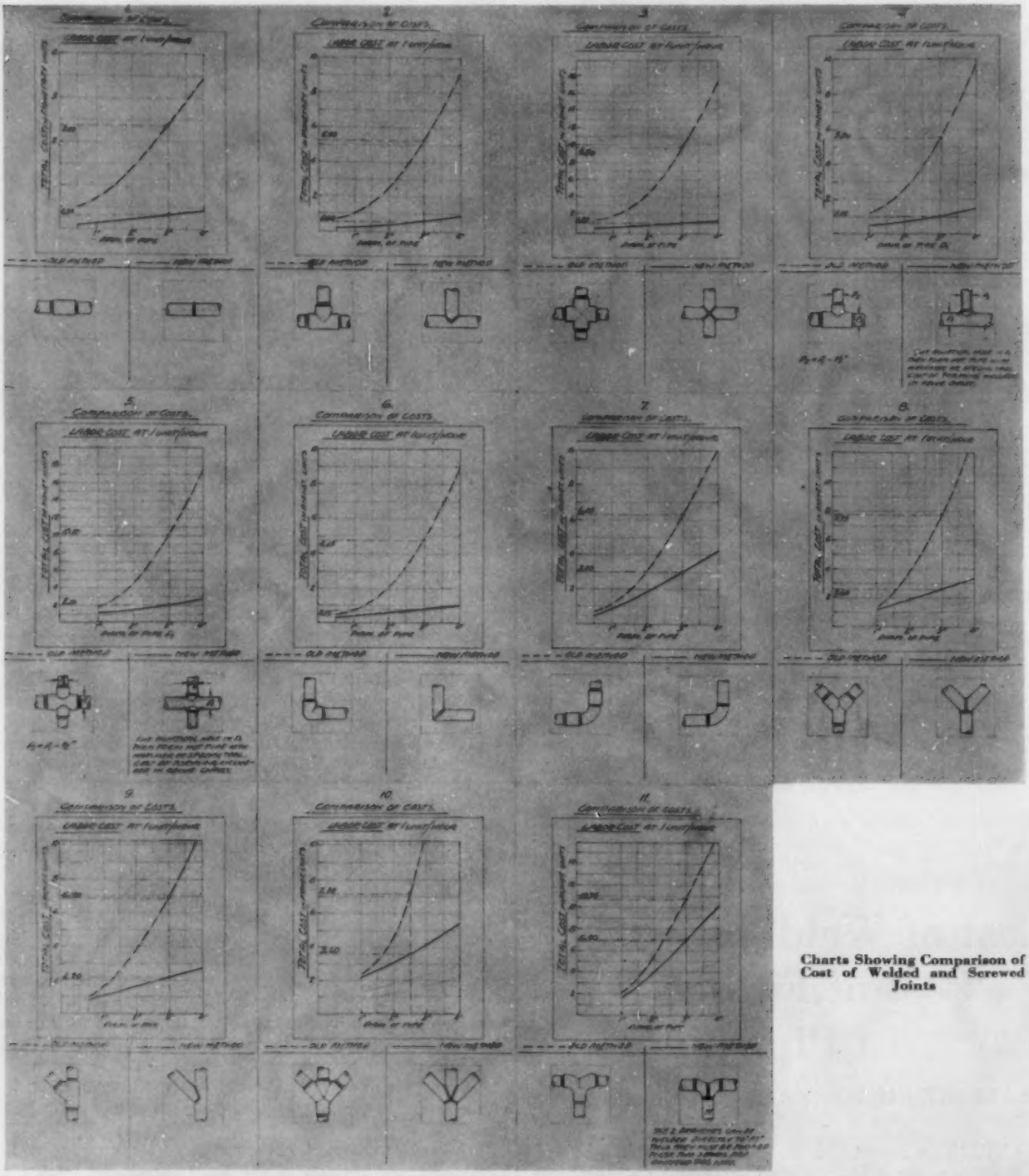
Oxyacetylene permits the highest working speeds, because no other welding gas mixture gives a greater temperature.

To avoid turbulent currents in gas, steam or water pipe-lines, one section of the joint should be beaten as shown on Charts 4 and 5. This can easily be done by applying heat to the pipe with a hammer or a tool made for just that purpose.

The accompanying charts show the comparison of cost of the old and new methods—the old-fashioned way of screwing the sections of a pipe-line together and the modern way of welding.

In the comparison of costs of both methods all expenses are included such as: labor, material, oxyacetylene, welding rod. These charts were made for another monetary unit than ours, but, nevertheless, they

point out the facts of the tremendous savings that can be effected with that new method. The labor costs are fixed at 1 unit per hour. Due to the lower cost of acetylene and oxygen in this country, welding gains another advantage (which has not been considered in the presented charts) over the old method.



Charts Showing Comparison of Cost of Welded and Screwed Joints

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WELDING SURVEY

A Monthly Review of Some Important Phase of Welding

Welding Corrosion-Resisting Steels

By OWEN C. JONES

✦Mr Jones is a member of the staff of the Technical Publicity Department, The Linde Air Products Co.

CIVILIZATION is finding today an ever-increasing use for corrosion- and oxidation-resisting alloy steels, and this advance demands for those who would use and manufacture things from these steels a thorough knowledge of the best method for their fabrication. Oxyacetylene welding is finding a widespread use in this direction. Many of these alloys on the market today bear special trade names, but they may be grouped according to various characteristics which are a result of their composition. Among the alloying elements generally used, chromium is the most important and useful in imparting the properties of oxidation and corrosion resistance. Many of these alloys also contain nickel.

With the great demand for welded products made of these alloys, it is essential that we know how to carry out the welding operations so as to assure completely satisfactory results.

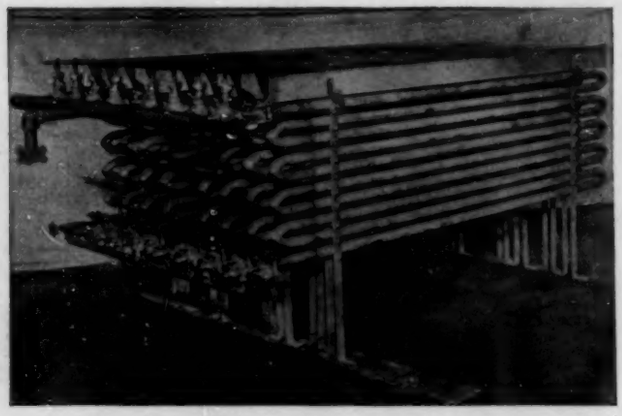
The data which follow describe the welding procedures for various of the high-chromium alloys. Under proper conditions and with correct procedure these can be welded successfully in practically all cases.

Commercial chromium alloys are divided in this article into eight groups in accordance with the different recommended procedures for welding and, since these methods are governed largely by the amount of chromium in the alloys, this percentage is used to show under which head the particular type of alloy is placed. The procedure given for a certain group will be the same regardless of the variations in chemical composition which may occur within the limits of the group. It should be remembered that the compositions shown in the respective tables are representative and nominal only.

Due to the formation of infusible oxides, consisting chiefly of chromium oxide together with smaller amounts of iron oxide, manganese oxide and silica, flux is used in welding these materials. The ordinary fluxes for welding or brazing are not satisfactory for these alloys. For this service the flux must be correctly compounded to dissolve readily the refractory chromium oxide and of sufficient viscosity at high temperature to protect adequately from oxidation the molten weld metal and metal adjacent to the weld. A flux, especially designed for welding high-chromium steels, known as "Cromaloy Flux," has been used with great success. It has a high solvent power for chromium oxide and is of suitable viscosity at the welding temperature. Best results are obtained through its use, and it is recommended that this flux be used in all cases.

Best results are secured with the use of a neutral flame. An oxidizing flame tends to give a porous weld with gas inclusions and should never be used. A reducing flame tends to increase the carbon content of the weld and base metal adjacent to the weld and reduces resistance to corrosion. This, however, can be largely controlled and many operators use a flame adjustment which shows a barely perceptible acetylene feather on the inner cone of

Welding Makes Stainless Steel Beer Barrels Practical



Corrosion-Resisting Steel, Welded Cooling Unit Used in the Manufacture of Beverages

the flame. A real reducing flame, except in special later-mentioned cases, is just as much to be avoided as an oxidizing flame.

Group 1—Stainless Steel

Chromium	12–15 per cent
Carbon	about 0.30 per cent

Stainless steels of this class are generally used for cutlery and heat-treated machine parts. If the full corrosion-resisting properties of this group are to be obtained, complete heat treatment is necessary after welding. Annealing, which gives completely satisfactory results for most stainless steels, does not restore full properties to this group. The welding procedure is the same as for Group 2.

Group 2—Rustless or Stainless Iron

Chromium	11.5–15.00 per cent
Carbon	max. 0.12 per cent

Irons of this class are used chiefly in sheet form. In thicknesses up to 16 gage, flanged type welds are ordinarily employed. All scale should be removed from the edges to be welded. The flanges, preferably about $^1/_{16}$ in. high, are painted top and bottom with a paste made by mixing Cromaloy flux with water. After this the weld is made in the usual way by melting down and fusing the flanges. A blowpipe tip just large enough to insure proper fusion should be used, since too large a tip would cause the molten metal to boil and would result in porous welds.

For thicknesses greater than 16 gage, welding rods of the same composition as the base metal, or low-carbon rod containing 15 to 18 per cent chromium will produce welds with satisfactory corrosion resistance for the conditions under which this metal is generally used. Good butt type welds can be obtained in metal $^1/_{16}$ in. to $^1/_8$ in. thick without beveling. Thicknesses greater than $^1/_8$ in. should be beveled. It is essential that the flux be applied to the line of the weld on both the top and bottom surfaces of the sheet. This prevents oxidation on the underside and allows good fusion and union to take place under the protecting film of slag. Without the use of this flux, it will be impossible to obtain complete fusion at the bottom of the seam. When a rod on which flux paste has been coated is used it is only necessary to paint the bottom sides of the seam with flux. To coat the rod it should be clean and painted with a thin mixture of Cromaloy flux and water.

In making welds in heavier gages of rustless iron, the plate should be beveled and both faces of the bevel coated with the flux. The welding should be carried through to completion rapidly and, if possible, the design of the weld should be of the single-vee type. Double-vee welds can be successfully accomplished with careful preheating, but this method is not recommended generally.

As a result of the high temperature attained during welding, rustless iron has a tendency to be brittle in the weld metal and in that portion of the sheet adjacent to to the weld unless properly heat treated after welding. Rustless irons, particularly those containing 12 to 14 per cent chromium, are subject to air hardening and require annealing to restore toughness to the weld and base metal adjacent to the weld. Best results are obtained by heating in a furnace at a temperature of 1250 to 1300° F. (675 to 705° C.) followed by slow cooling, either in the furnace or in warm still air.

The blowpipe is often utilized for applying the heat in cases where it is not possible to use furnaces. When using this method of annealing, care must be exercised not to heat the metal above the maximum temperature previously mentioned. The benefit to be derived from blowpipe annealing will depend on the care used in controlling the temperature and time of heating. Usually three minutes within the above temperature range will give the desired softening effect.

The higher silicon content found in some of the commercial grades facilitates welding and reduces their tendency to air-harden. They are, however, more subject to grain growth in the weld and base metal adjacent to the weld. Excessive grain growth results in a brittle condition which in most cases can be remedied, particularly on light-gage metal by annealing at 1250 to 1300° F. Blowpipe annealing for three minutes within this temperature range softens somewhat the weld and adjacent metal. After furnace treatment, welds in 16-gage material will stand considerable bending without fracture.

Rustless iron also can be bronze-welded successfully. It is necessary that the surfaces to be bronze-welded be clean and free from oxide. A combination of Cromaloy flux and a good bronze welding flux should be used. A mixture of 75 per cent Cromaloy flux and 25 per cent Brazo flux works very satisfactorily. When bronze-welding is used, no after-annealing is necessary or advisable as the application of bronze to steel takes place at a temperature lower than that which affects the properties of the iron. To heat-treat after bronze-welding will also be apt to melt off the bronze. Obviously, where a color match is not necessary the use of bronze-welding will have many attractive considerations. Its strength is

Weight Reduction, Strength and Resistance to Salt Water Action Accomplished by Use of Welded Chromium Steel for Seaplane Pontoons

high on the order of 55,000 lb. per sq. in. and it has good resistance to corrosion.

Group 3—Stainless Iron

Chromium	15–18 per cent
Silicon	0.50–1.25 per cent
Manganese	max. 0.50 per cent
Carbon	max. 0.10 per cent

In this group best results will be obtained by the use of a welding rod of the same composition as the base metal. A splendid weld also can be made that fulfils in every way the requirements with 18 per cent chromium–8 per cent nickel welding rod. The metal adjacent to the weld is subject to some grain growth but annealing at 1200 to 1350° F. (650 to 750° C.) will improve its ductility. With careful welding the grain growth is kept to a minimum.

Here again, as in the case of rustless iron, Cromaloy flux should be used to insure uniform results. The technique and procedure outlined for Group 2 for the actual welding operation should be used.

Group 4—18 Per Cent Chromium–8 Per Cent Nickel Alloy

Chromium	16–20 per cent
Nickel	7–12 per cent
Silicon	max. 0.75 per cent
Manganese	max. 0.65 per cent
Carbon	max. 0.12 per cent

The group of steels containing 18 per cent chromium and 8 per cent nickel commonly known as 18–8 are joined without difficulty by welding. The welds are strong and tough, but in severe conditions of corrosion the welds and particularly the adjacent base metal may be slightly less resistant to corrosion than the base material due to a precipitation of carbides brought about during the welding. If severe corrosion conditions are to be encountered by the welded alloys containing over 0.07 per cent carbon a heat treatment at 1800–1900° F. (1000–1050° C.) followed by water quench will restore the corrosion-resistant properties. The farther the carbon is reduced below 0.10 per cent, the greater will be the resistance to corrosion, and at about 0.04 per cent the alloy in the as-welded condition is practically free from the intergranular corrosion.

In welding, the shorter the time the metal is held between the temperatures 1470–1652° F. (800–900° C.), and the faster the cooling from the higher temperature, the better the subsequent resistance to corrosion. For this reason and also to hold warping of the metal at a minimum, the welding should be done rapidly and with the least possible heating of the metal adjacent to the weld.

Drift Test on 18-8 Steel Welded Tubing Shows the Welds Stand Expansion as Well as the Steel

The oxyacetylene process is particularly recommended for welding sheet $^1/_{16}$ in. or less in thickness, and it may be used for sheets of greater thickness if continual care is used to reduce as much as possible the amount of heat going into the weld. On heating, the alloy has a high coefficient of expansion, which accentuates its tendency to warp. This difficulty can be controlled by jigs or other fixtures to hold the sheets in place during welding and at the same time limit the heat absorbed by the base metal. Careful preheating of large surfaces in special jigs is sometimes used to prevent distortion during welding.

Edge welds, when made over a suitably grooved backing-up strip and in clamping jigs to control warping, present a smooth appearance on both top and bottom surfaces.

During welding it is essential that a flux be applied, particularly to the underside of the seam to be welded. This application of flux prevents atmospheric oxidation on the underside and allows the bottom edges of the parts being joined to flow together, yielding a dense weld at the bottom of the seam. Flux may be applied to the rod if required, but in all cases it is essential to apply it to the underside of the seam.

Crush Test on Chromium-Nickel-Iron Tubing. The Welds Showed No Signs of Failure

Group 5—24 Per Cent Chromium–12 Per Cent Nickel Alloy

Carbon	max. 0.25 per cent
Chromium	20–30 per cent
Nickel	10–22 per cent
Silicon	0.5–1.5 per cent

This steel is used for resistance to oxidation at high temperatures, and resistance to corrosion is not an important factor so far as joining is concerned. However, under some severe corrosive conditions welds in this alloy are subject to intergranular corrosion. Because it has a high coefficient of expansion and low heat conductivity, more than the usual allowances should be made for contraction during welding. The backhand method of welding is preferable for retarding contraction. A generous application of flux should be made, especially on the bottom of the edges to be welded, because the slag formed on the melted metal is sluggish. Good quality welds are readily obtained by careful adherence to the correct procedure.

On account of their high chromium content this group of alloys presents some difficulties in welding when the material is more than 1/4 in. thick, due to the formation of infusible oxides or slag. Fluxing helps this considerably. When subjected to the heat of welding, this metal undergoes considerable grain growth with resulting brittleness. This condition cannot be removed by annealing.

The best results are obtained by using a flame adjustment barely on the reducing side of neutral with flux. Welds may, however, be made in the metal with an excess acetylene flame without the use of flux, bearing in mind the fact that the welds will be hard, brittle, high in carbon and less resistant to chemical corrosion than the plate. This method of welding is sometimes used for boxes and containers which are not to be subject to very severe service conditions. A backhand welding technique should always be used.

Group 6—Nickel-Chromium Alloy

Carbon	0.30–0.50 per cent
Nickel	21.00–25.00 per cent
Chromium	7.00–9.00 per cent
Silicon	1.00–1.50 per cent
Copper	1.00–1.50 per cent

Alloys of composition within the above ranges and others with varying amounts of nickel, chromium and silicon may be welded with very satisfactory results. On account of their high expansion properties, provision should be made for controlling expansion and contraction, the same as with other alloys. With the higher nickel content the weld metal is quite liable to be weak just after solidification, and care should be taken to insure freedom from stress during solidification. In all cases procedures as described under the welding of rustless iron, Group 2, should be followed.

Group 7—Chrome Iron

Carbon	max. 0.30 per cent
Chromium	24–30 per cent
Manganese	0.50–1.00 per cent
Silicon	max. 0.60 per cent

The welded chrome iron will not stand severe mechanical treatment at ordinary temperature, but is quite ductile at temperatures above 932° F. (500° C.), and as this is its principal service, namely, to resist oxidation at very high temperatures, welded joints can be used wherever desired.

Chrome iron, as this alloy is commonly called, has about the same coefficient of expansion as steel and accordingly about the same allowance should be made for expansion and contraction. Welding rods of the same composition as the base metal should be used. The edges of the weld should be prepared the same as for steel of like thickness. In order to secure good bottom fusion the application of a paste of Cromaloy flux to the underside of the seam will prevent atmospheric oxidation and allow the bottom edges to fuse together. Without flux on the underside severe oxidation will take place, leaving a groove at the bottom of the weld. A small amount of flux applied to the rod will facilitate welding in preventing oxidation of the rod at the end. In making a weld only enough heat to secure satisfactory fusion should be used. Overheating causes boiling and results in porosity. The welds should be made as rapidly as possible and should be carried through to a finish without delay.

In welding castings it is preferable to preheat and weld with a rod of same composition as the base metal, using as little heat as possible and a neutral flame. If the castings are high in carbon as in castings for wear resistance, the use of an excess acetylene flame is permissible. It will facilitate the welding, allowing sand and oxide to be floated more easily. Any blowholes should be ground out, if possible, exposing clean surfaces for welding. Slow cooling, after welding, is advisable. If heat treatment is required to impart special properties to the casting, this should be done after cooling down from the welding operation, or the casting after welding may be

Welded Tubing, 18 Per Cent Chromium–10 Per Cent Carbon. The Unbroken Welds Are at the Apex of Right-Hand and Right Edge of Left-Hand Specimen

brought up to the desired uniform temperature without allowing it to cool down. This last procedure will eliminate stresses from uneven cooling. Annealing after welding is recommended.

Group 8—Castings

High chromium alloy castings, with wide variation in contents of chromium or chromium and nickel, are in extensive use. They may contain also appreciable amounts of silicon. Castings, as a rule, contain considerably more carbon than the rolled products. The castings may be used for resistance to chemicals, heat or wear, the composition being determined by the use.

For welding castings containing high carbon and designed for wear resistance, it is preferable to preheat to a good red heat to avoid cracking the metal. Cooling should be relatively slow; after this the castings may require further heat treatment to produce the necessary hardness. Welding rods of the same composition as the base metal should be used. The use of flux will facilitate fusion and assist in removing oxide and sand spots in defective castings.

After welding the casting should be reheated to an even temperature and cooled slowly. Following this, further heat treatment may be necessary in order to produce the desired physical properties in the metal.

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In conclusion, it may be said that the successful oxy-acetylene welding of high-chromium stainless and rustless steels and irons depends chiefly upon certain particular factors. It is always necessary to have a clean surface on the base metal and either a rod of the same composition of the base metal or another which is known to produce the desired results. A neutral flame is recommended in all cases except in those specifically stated otherwise, although a flame with a very slight excess of acetylene may

be used. A flux with special characteristics, such as Cromaloy, is necessary.

Stainless steels and irons can be properly and satisfactorily welded by the oxyacetylene welding process in accordance with the procedures just outlined. Full advantage should be taken of this since welded stainless steel products have, as an added feature to their corrosion-resisting properties, the fact that they are welded. This in itself is an important factor in adding strength, permanence and neat appearance to manufactured articles. A welded stainless steel product is a more salable product since it is a better, stronger and more lasting product.

Arc Welding of Corrosion-Resisting Steels

By **A. F. DAVIS**

✦Mr. Davis is Vice-President of the Lincoln Electric Company.

AN INTERESTING application of the use of welded alloys to resist corrosion was described in a paper by Raymond S. Hoffman, Standard Oil Company of New Jersey, submitted in the recent Lincoln Arc Welding Prize Competition. Mr. Hoffman explained the use of arc-welded alloy-lined fittings in high pressure cracking apparatus for oil refineries. After being in service approximately 22 months, these fittings had saved over 59 per cent of the cost of old-style fittings.

Such pipe-line joints are usually made with carbon steel flanges, valves, crosses, etc. Due to the corrosive action of "sour" crude oil, the life of these fittings is as low as six months and few last over a year. The lined fittings have an indefinite life and are much less expensive than solid alloy fittings.

A typical fitting is shown in Fig. 1, a nozzle for a "soaking" drum. This is a carbon steel unit, with the flange counterbored $^1/_2$ in. deep and $1^3/_4$ in. wide into which the alloy metal has been deposited by means of the electric arc and a coated $^5/_{32}$-in. KA2 electrode. The V-shaped groove shown is machined into the deposited alloy metal to receive a metal ring gasket used in this type of high pressure, high temperature apparatus. The nozzle was first lined with an alloy sleeve. This was a very simple job, the sleeve cut to proper length being driven into position before the arc-welded deposit was applied to the counterbore.

Some of the figures showing savings made through the use of these alloy-lined fittings are interesting. These are typical:

Description	Life of Unlined Fitting	Life of Lined Fitting	Cost Unlined	Cost Lined	Solid Alloy
3-In. Cast Steel Flanged Tee	6 mo.	Indefinite—22 mos. service and still good	$18.54	$21.89	$ 54.24
6 x 4 x 4 Cast Steel Flanged Tee	6 mo.	Indefinite—22 mos. service and still good	$15.91	$26.00	$125.00
4-In. Nozzles	1 yr.	Indefinite—18 mos. service and still good	$40.00	$46.50	$ 78.85

Wherever metals must withstand corrosive action, the stainless steel alloys can be used effectively and economically; those most commonly used can be arc welded with little difficulty.

The application of linings of stainless steels, utilizing the electric arc, as outlined above, can well be adapted to many other industries and will show just as remarkable savings.

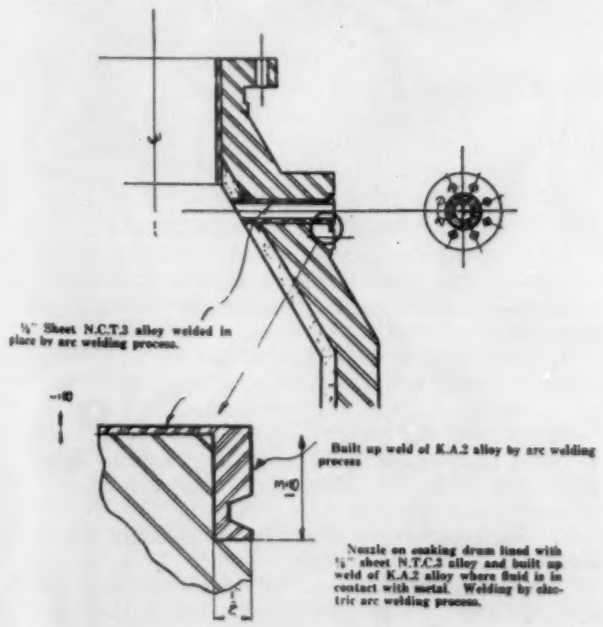

⅛" Sheet N.C.T.2 alloy welded in place by arc welding process.
Built up weld of K.A.2 alloy by arc welding process
Nozzle on soaking drum lined with ⅛" sheet N.T.C.2 alloy and built up weld of K.A.2 alloy where fluid is in contact with metal. Welding by electric arc welding process.

Fig. 1

The Welding of Corrosion-Resisting Steels

By **CHAS. H. JENNINGS**

✦Mr. Jennings is connected with the Westinghouse Research Laboratories.

Introduction

THE rapid increase in the use of corrosion-resisting steels (chrome and chrome-nickel alloys) and the development of fusion welding for fabricating the same, necessitates that welders, foremen, superintendents and engineers who are connected with welding become familiar with the welding methods and processes employed. It is the purpose of this article, therefore, to briefly summarize and condense some of the available information on the arc welding of corrosion-resisting steels and present it in a concise, non-technical form.

Classification and Characteristics of Corrosion-Resisting Steels

From the view-point of weldability, most commercial chrome and chrome-nickel alloys can be divided into three general classes:

1. Chrome alloys containing 14% chromium or less (susceptible to air hardening).[1,2,3]
2. Chrome alloys containing over 16% chromium (not appreciably susceptible to air hardening).[1,2,3]
3. Chrome-nickel alloys (austenitic class).

A. Chrome Alloys Containing 14% Chromium or Less.—This class of alloys is susceptible to air hardening. As a result welds made on them will be hard and brittle. This condition is so severe that cracks may develop in the weld or in the parent metal, adjacent and parallel to the weld, during the welding process. Partial restoration of the ductility and toughness can be obtained by heat treating at 1200–1400° F. for 15 or 30 min. and cooling slowly. Care must be taken not to heat the material over 1450° F.

The low-carbon alloys of this class (carbon below 0.20%) do not require heat treatment to develop their corrosion-resisting properties. The high-carbon alloys of this class (carbon 0.20% or over) are dependent upon heat treatment with rapid cooling and good surface finish for their corrosion-resisting properties. The fact that the high-carbon alloys require heat treatment and slow cooling to improve their physical properties and heat treatment with rapid cooling to develop their corrosion properties makes them generally unsuited for welding.

B. Chrome Alloys Containing Over 16% Chromium.—Alloys of this class are not appreciably susceptible to air hardening and have the property of retaining their corrosion resistance at high temperatures. The fact that they are not appreciably susceptible to air hardening, however, does not result in their being satisfactory to weld. The heat produced by welding causes rapid grain growth which results in a joint that is hard and brittle at normal temperatures. Heat treatment will not correct this condition and as a result alloys of this class are not recommended for welding except in special cases.

At temperatures of 400–800° F. welded joints in alloys of this class have considerably improved properties. This characteristic, combined with the low expansion properties of these alloys (the expansion properties will be discussed later), makes them suitable for welding when the working temperatures are around 400–800° F.

C. Chrome-Nickel Alloys (Austenitic Type).—The most universally used alloy of this class is the 18–8 type (18% chromium and 8% nickel). Consequently, it is the only one that need be discussed. This alloy is the most easily welded of all the corrosion-resisting alloys. The welds and parent metal are not subject to air hardening or grain growth and the resulting welds are soft, ductile and strong. The physical properties of welds made on this alloy are as follows: ultimate strength 65,000–75,000 lb. per sq. in.; yield point 40,000–50,000 lb. per sq. in. and elongation 15% in 2 in. Heat treatment is not required to improve the physical strength of the welds, although it has a beneficial effect in relieving the welding strains and slightly increasing the ductility and tensile strength.

In alloys where the carbon content is over 0.07% the heat of welding will cause carbon to precipitate at the grain boundaries, thereby lowering the resistance of the weld and surrounding metal to corrosion. For carbon contents below 0.07% no trouble is experienced from this phenomenon. Heat treating at 1800–2000° F. and quick cooling will put the carbon back into solution and restore the corrosion-resisting properties. (For small and thin pieces air cooling is sufficiently rapid. For large pieces water quenching is necessary.) The decrease in corrosion-resisting properties resulting from carbide precipitation is not severe and in many cases heat treating is not necessary even though carbon precipitation has occurred.

Welding Procedure and Technique

The welding procedure and technique employed in welding the above three classes of corrosion-resisting steels are practically the same, consequently they will be discussed together.

The welding of all the alloys should be done with fluxed electrodes using reverse polarity. (The use of reverse polarity is not a hard and fast rule.) The composition of the electrodes should, in general, be the same as that of the material being welded. In certain cases, such as where rigid joints in chrome-steel alloys are being welded, it is advisable to use chrome-nickel electrodes because of the superior ductility of the welds obtained.

The electrical resistance of all the chrome and chrome-nickel alloys is relatively high, therefore the electrodes quickly become heated from the current flowing through them. In order to keep the electrodes from over-heating and destroying their flux it is essential that not more than 7 or 9 in. of electrode be consumed at a time. If 18-in. electrodes are used it is desirable to grip them in the center and weld from both ends. If it is necessary to grip them at the end, only half the length should be consumed at a time. The remaining half should be allowed to cool before using.

Chrome-nickel electrodes should not contain more than about 0.07% carbon and their flux should be free from carbonaceous materials. Carbonaceous materials will break down in the heat of the arc and carburize the weld metal, thereby making it more brittle and less resistant to corrosion.

The thermal conductivity of chrome-nickel alloys is from 30 to 50% of that of mild carbon steel. The thermal conductivity of the chrome alloys is somewhat greater than the above but they are still considerably below the values of mild carbon steel. This low thermal conductivity retards the transmission of heat from the weld to the surrounding material, consequently special precautions must be taken to prevent over-heating. Several of the most common methods of preventing over-heating are as follows:

1. The welding currents used should be about 80% of the values used for mild carbon steel electrodes. (This also aids in preventing excessive heating of the electrodes.)
2. The molten metal should not be puddled. Puddling prolongs the length of time the arc is held in a given spot and tends to produce excessive heating.
3. It is often better to deposit several light layers of weld metal instead of one heavy layer. The deposition of a heavy layer produces a heating effect similar to that produced by puddling.
4. Back-up strips of copper will aid in conducting away the heat.

The coefficient of expansion of the chrome alloys of the air-hardening and non-air-hardening class is about 25% less than that of mild carbon steel. As a result

[1] This is an approximate and not a fixed dividing point. Also the susceptibility to air hardening varies to a certain extent with the carbon content.
[2] T. Holland Nelson, "Riveting and Welding Rustless Structures," *Iron Age*, Vol. 128, No. 15.
[3] J. H. G. Monypenny, "Stainless Iron and Steel."

the expansivity of these alloys offers no difficulty from the standpoint of welding.

The coefficient of expansion of chrome-nickel alloys, however, is about 50% greater than that of mild carbon steel. This high coefficient of expansion offers considerable difficulty from the standpoint of welding and must be taken into consideration. Proper fixtures and clamps should be used to prevent warping and distortion.

The joint preparation for corrosion-resisting steels is similar to that for mild carbon steel. Scarfing is not required on plates $^1/_8$ in. thick or less. Plates $^3/_{16}$ in. thick and over should be scarfed. When butt welding thin-gage material the butting edges should be turned up about $^1/_{16}$ in. to form a so-called double flanged butt joint.

The welding operation will produce a discolored and corroded area on each side of the weld. This should be removed by pickling or grinding so that it will not start corrosive action.

Both direct current and alternating current welders are suitable for welding corrosion-resisting steels. Alternating current welders equipped with a short wave arc control are particularly adapted to this class of work because of the stability of the arc obtained.

FROM ABROAD

Electric Arc Welding under Water

By **PROF. K. HRENOFF** *and* **ENG. M. LIVSHITZ**

+Prof. Hrenoff and Eng. Livshitz are with the Moscow Electromechanical Institute of Transport Engineers.

IN FEBRUARY 1932 the Welding Research Laboratory of the Moscow Electromechanical Institute of Transport Engineers began studying the problem of the possibility of arc welding under water. As we know, the burning of the arc in a liquid medium is not so stable as in a gas one, and the extinction of the arc by a liquid medium is, for example, used in oil-break switches. The burning of the arc in water and other liquids was for the first time discovered and studied by G. Bredig and used for pulverizing of metals and preparing colloidal solutions of same. The first experiments of this kind were realized in 1898 (*Zeitschrift für angewandte Chemie*, 951 (1898)).

Experiments on pulverizing electrodes by arc burning in a liquid medium were later on made by Swedberg, Billiter, W. Ostwald and other investigators. The burning of the arc in different liquids is used since that time, for instance, in order to obtain colloidal solutions of different matters.

While the arc is burning in the liquid, the vapors of the electrode metal are coming into contact with the surrounding water and consequently condense into very fine particles, floating in water and forming colloidal solutions of the metal or its oxides. Iron and aluminum oxidize and their oxides form colloidal water solutions. Many non-metallic substances introduced into the arc and turned by the arc into vapor inside a liquid medium may also be subjected to a similar pulverization, colloidal water solutions being formed.

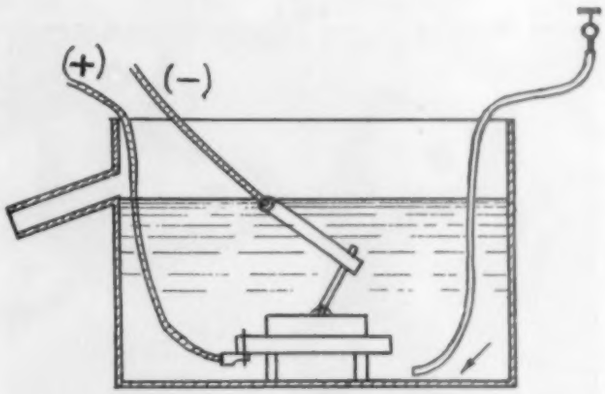


Fig. 1

The possibility of under-water arc welding has apparently never been investigated before. For the performing of experimental work at the laboratory a square 3-mm. sheet iron tank was made with its upper end open. At the beginning of the experiment the tank was filled with fresh water, pipe or salted (2% of salt) water, the latter replacing natural sea water. There being an outlet pipe, the water in the tank could be made running. An iron welding table was set at the bottom of the tank, and a wire from the source of the welding current was joined to it. The object of the welding was put on the table. The electrode with the holder was plunged into the water. The general disposition of the experimental equipment is shown by Fig. 1.

A set with a welding current up to 300 amp. served as a source of welding current for working with a direct current arc, while for the work with an alternating current arc a welding transformer with a current up to 250 amp. was used. The welder would put on long, up-to-the-elbow rubber gauntlets before work. No helmet or face-shield was used for the welder as the water layer reduced the arc radiation to the extent of eliminating any detrimental influence on the welder's eyesight, in transitory laboratory experiments at least.

The very first experiments with ordinary thin-coated electrodes displayed the possibility of the drawing of the arc inside the water between a steel electrode and the object of welding, the arc being fed by a normal welding machine. A certain amount of training done, the welder succeeded in keeping the arc burning for a few seconds, but not in obtaining the process of normal welding with a proper bead laid on. At the places affected by the arc at the surface of the plate small cavities were observed in the base metal which bore signs of smelting, as well as separate drops of deposited metal not cohesive with one another and badly cohesive with the base material. Bare and fluxed with different coatings, mild steel electrodes of various diameters were successively used, the results not proving satisfactory. Some more or less satisfactory results were obtained by using certain kinds of thick-coated mild steel electrodes, the coating containing iron oxides. This made us start a research after a special coating for under-water welding. Our experiments proved successful. Electrodes of mild steel, containing 0.13–0.2% of carbon, were used. The coating was multilayer. The first layer was prepared of chalk powder mixed with a water solution of liquid glass, the following layers consisting of a fine powder of iron oxide mixed with 2% of magnesium carbonate that was also mixed with a water solution of liquid glass. The experiments proved the good quality of such electrodes and subsequent experiments were made with electrodes of our own making. The coating of the electrodes was done by plunging them into an adequately composed

Fig. 2

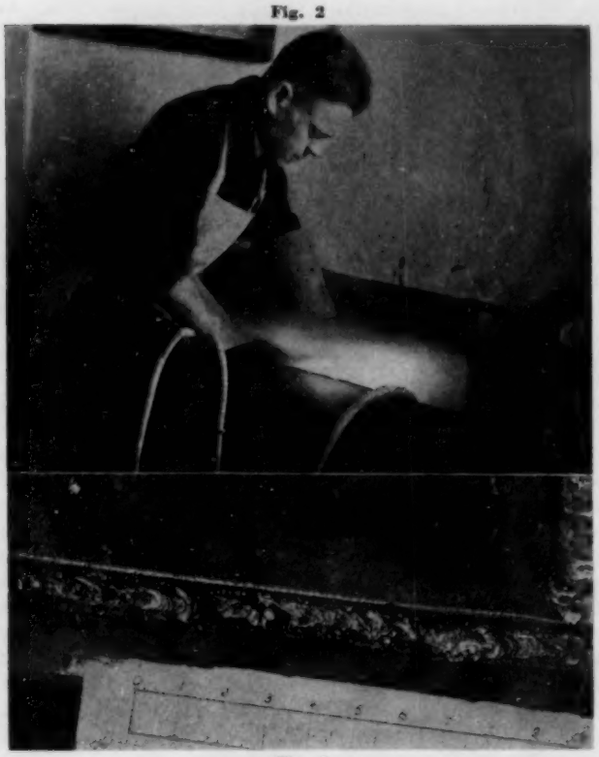


Fig. 3

paste and by subsequently drying them at a surrounding air temperature.

The electrodes, however, proved unsuitable in sea water and had to be coated with spirit-shellac varnish after the coating had been dried. This was necessary because there would begin a vigorous electrolysis when a non-varnished electrode would be plunged into salt water. The electrolysis would disintegrate the coating and make further work utterly impossible.

The varnishing of the surface of the electrode was done by plunging it into an adequately composed solution. After varnishing, the electrode was dried. The varnishing of the surface of the electrodes makes the coating watertight and non-hygroscopic, which conditions, as shown by further experiments, are absolutely necessary for welding in sea water. The varnishing of electrodes improves the working conditions in fresh water as well, and consequently may be recommended for all cases of under-water welding.

The experiments were made chiefly with direct current welding, with alternate current having shown a far less stability for the very simple reason of the extinction of the arc when the value of the current is equal to zero. The welding is performed easier at normal polarity (electrode negative), and with this polarity our basic experiments were made, although experiments using a reverse polarity are possible.

Electrodes of different diameters—from 3 to 7 mm.—were tested. In order to obtain a stable, arc electrodes of a diameter not less than 4 mm. should be used. In experiments where direct current and normal polarity were used, and the electrodes were of our own make, the following welding conditions proved optimum:

Diameter of the Electrode, Mm.	Welding Current, Amp.	Working Voltage, Volts	Open Circuit Voltage, Volts
7	190–210	35–40	85–95
5	160–180	30–35	80–85
	150–175	28–30	75–80

The 150 amp. value of the welding current is a minimum and, if diminished further, does not provide a proper bead.

As is shown in the table, the value of the welding current does not change essentially as the diameter of the electrode changes, and the working voltage is 10–15 volts higher than during air welding.

After having acquired certain skill, the welder could keep the arc burning stably about as easily as in the air.

The examination of the electrode end after the burning of the arc showed that the metal of the electrode melted a little sooner than its coating; the electrode end had a form of a cup surrounded by a projecting border of the coating. This facilitated the work when visibility was not good enough. The welder could work by "groping" or touching the surface of the object of welding with the edge of the projecting border of the coating from time to time, thus regulating the length of the arc within

Fig. 4 Fig. 6

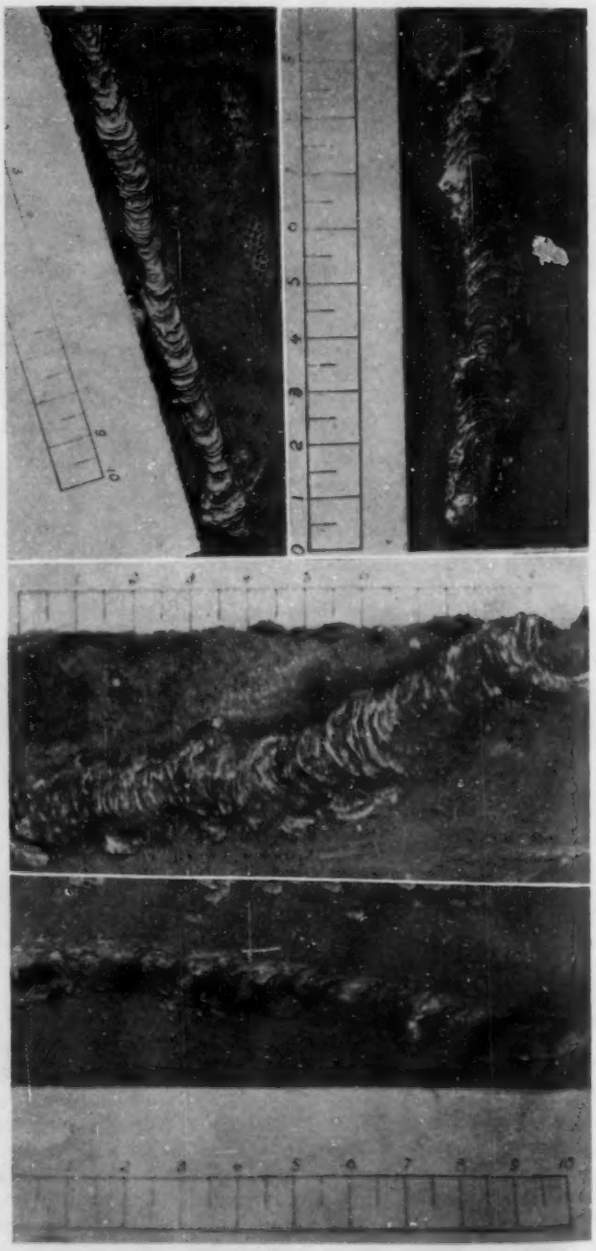


Fig. 5 (Center) Fig. 7 (Lower)

Fig. 8 Fig. 12

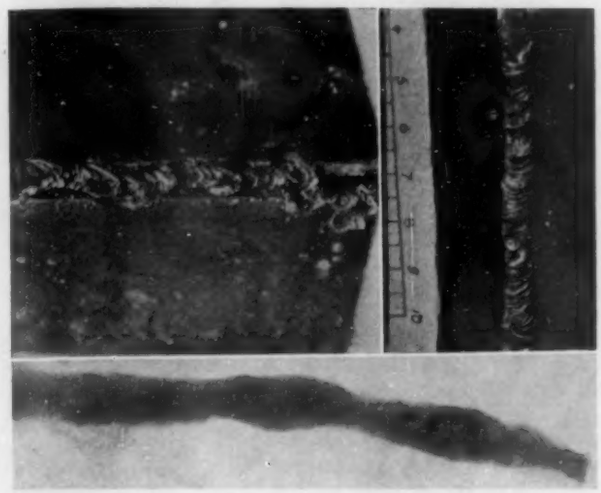


Fig. 9

necessary limits. If the length of the arc and the speed of the motion along the weld were normal, the welder obtained a bead, quite good from the outside. A narrow, as well as a widened bead, could easily be obtained if the electrode were moved in a zigzag way. There was intense pulverizing action of the under-water arc upon the base metal. Apparently, the relative melting of the base metal was performed sooner in under-water welding than in air welding, while the melting of the electrode and the deposit of the electrode metal proceeded slower in under-water welding. The cutting activity of the arc was also higher, hence, any accidental impediment of the arc might cause a cut through the material or the burning of holes in it much more readily than would be possible in an air welding with the same value of current.

The water surrounding the arc was in a state of intense turbulence. Rather big gas bubbles rose to the top and sometimes burned on the surface without exploding. They obviously contained hydrogen. A turbidity of the material pulverized by the arc was formed around the arc and soon the water became dark, the turbidity settling very slowly. The whirling of the water, the forming of gas bubbles and the colloidal turbidity over the arc made it practically impossible to discern any details at the point of welding when it was watched from above as was the case in our experiments. Neither the arc, nor the electrode end, nor the outline of the weld could be seen. The whole welding zone blended into a dim, light, moderately bright envelope flame which could be looked at with a naked eye without tiring the latter.

The brightness of the envelope flame may be judged, to a certain extent, by Fig. 2, presenting experimental welding. The radiation of the arc is reduced by the water layer to an extent of apparently doing away with any danger for the welder. The welder never protected his eyes during the work.

Our attempts at improving the visibility in some way or other proved unsuccessful, and it is obviously practically impossible for the welder who is outside the water and watches the process from above to obtain a proper visibility. It is however supposed, and with reason, that if the welder is in the water, wearing a diving dress, and if he watches the arc from a side or from below, he can see the welding much better. This assumption, which could not be proved under laboratory conditions was fully confirmed later on under conditions of ordinary practice, when the work was fulfilled by welder-divers in the sea. It is practically very difficult to place the welder into water to fulfill under-water work if the depth is not great enough. We had, therefore, obviously to continue with the bad visibility of the welding. Under-water welding may be more or less satisfactorily fulfilled even with a bad visibility in many occasions. Sometimes the welder can feel the direction of the seam with his unoccupied left hand or use a template for directing the electrode. A projecting part of the weld, for instance the edge of the upper sheet of an overlapping weld, may often be very useful for directing the process. We managed to weld overlapping seams successfully under laboratory conditions, using the upper edge as directing, but butt-welds were made with a great deal more difficulty, the welder, as a rule, losing the direction of the weld and wandering away from the centerline.

One of the most convenient tasks under bad visibility is the overlapping of a patch consisting of a piece of iron sheet laid on a gap or crack, as is shown by Fig. 3.

Besides welding in a flat position we made experiments on vertical and overhead under-water welding. These kinds of welding proved fully possible, and their fulfillment did not present any special difficulties. Welding on vertical surfaces is possible in all directions; the deposition of upright fillets upon a vertical surface from the top downward is better than if welding in the opposite direction. Figures 4–9 show some samples of under-water welding done by the laboratory:

Figure 4—A deposited narrow bead; the thickness of the material is 5 mm., the electrode is made of mild steel, the coating is prepared by the laboratory, the diameter is 7 mm., the value of the current is 200 amp.

Figure 5—The same, a widened bead, a 4-mm. diam. of the electrode; the value of the current is 170 amp.

Figure 6—The same; the bead is on a vertical surface, the thickness of the material is 10 mm., the diameter of the electrode is 4 mm., the value of the current is 180 amp.

Figure 7—The same; the diameter of the electrode is 7 mm; the value of the current is 230 amp.

Figure 8—A corner welding of plates; the thickness of the material is 5 mm., the diameter of the electrode is 7 mm., the value of the current is 200 amp.

The accomplished beads and welds were subjected to some investigations by us.

The hardness test showed the following average figures for several samples:

Base metal—117 (Brinell)

Deposited metal—164 (Brinell)

(The work was done with mild steel electrodes.)

These data show that the hardness of the deposited metal increases but remains within allowable limits and should not arouse any fears. The density of the deposited metal was tested by X-raying. The X-rayed samples proved to be denser than is usual for air welding. One of the X-ray photos, showing the density of the deposited

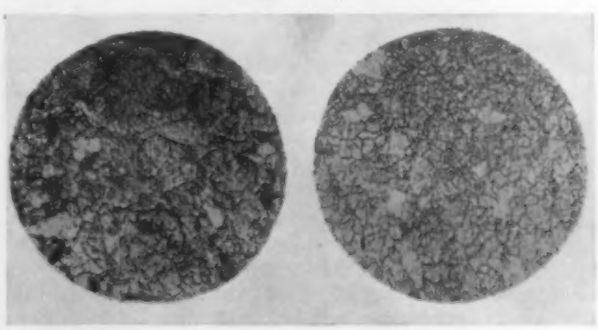


Fig. 10 Fig. 11

metal and a minimum amount of pores and inclusions, can be seen on Fig. 9. The density testing of some welds by moistening them with petroleum presented successful results.

The technological test was made by bending a 10 mm. thick plate together with the deposited bead set perpendicularly toward the axis of the bend. The first cracks appeared when the angle of bending was 70–90°.

The strength of the welds was determined by tensile tests of 3 samples of 50 mm. wide bars joined by a two-side lap weld.

The Results of the Strength Tests

No. of the Sample	Thickness of the Material, Mm.	Weld Length, Mm.	Height of the Fillet, Mm.	Breaking Load, Kg.	Ultimate Strength, Kg./Mm.^{2}
1	4	50	2	3550	17.5
2	6	50	4	6125	15.3
3	6	50	3.4	9400	27.6

The difference of the results displays that the bad visibility under the conditions of our experiments prevented the welder from acquiring efficient experience to make welds of similar strength.

The low strength thus obtained may, nevertheless, be considered satisfactory for a number of wreck repair works, for blocking up gaps, for under-water work, for salvage work, etc. Greater strength welds can undoubtedly be obtained if visibility is improved, for instance, if there is a welder-diver.

The investigation of the macro- and microstructure of the deposited metal gave very good results. The polished cross section of the bead, if watched through a magnifying glass, does not seem to contain any pores, inclusions or signs of poor penetration.

The line of fusion of the deposited and the base metal was utterly unnoticeable before the etching of the polished section.

Figure 10 shows the microstructure of the zone of fusion of the deposited metal and the base metal 180 times enlarged. The finer structure is that of the base metal. Figure 11 shows the structure of the base metal 180 times enlarged. These photos show clearly the good quality of the deposited metal.

We made four basic experiments in fresh water. Afterward we began welding experiments in sea water, instead of which we took a 2% salt solution.

For welding in sea water the coating of the electrodes had to be made watertight enough. This was obtained by varnishing the surface with spirit shellac varnish. After varnishing, the electrodes were thoroughly dried. Electrodes thus varnished proved to be quite stable in sea water; the disintegration of the coating was eliminated and the process of welding was performed about in the same way as in fresh water.

We suppose that welding in sea water under practical conditions would not be too difficult as compared with welding in fresh water. Later on we deemed it convenient to use varnished electrodes in welding in sea water also. It can be easily noticed that the melting and cutting activities of the arc are more intense in under-water welding than in air welding. Hence, it is only natural to expect the metallic arc to be fit for under-water cutting. Our experiments have proved this assumption; the under-water cutting of sheet iron is performed quite easily, a relatively clean cut being obtained. Holes are easily cut, for instance, through 10-mm. sheet iron, the diameter of a hole being only a little bit larger than that of the electrode. We experimented with a carbon arc also. Amorphous carbon electrodes of a 12-mm. diam. were taken, the value of the current being about 300 amp. and the voltage of the arc 40–50 volts. We obtained a stable burning of the carbon arc under water. Under-water cutting by a carbon arc and welding without supply of filler metal is quite practicable. A sample weld by a carbon arc under water is shown by Fig. 12. Two iron plates 3 mm. thick are corner welded, the edges being smelted without filler material. The welding is done by a carbon electrode of a 12-mm. diam., the value of the welding current being 300 amp. and the voltage on the arc 45 volt. The carbon arc welding was performed with direct current and straight polarity. Carbon arc welding with filler metal proved extremely difficult under the conditions we had, owing to the bad visibility of the welding place, which is the main obstacle of the metallic electrode welding as well.

The visibility of carbon arc welding will in all probability be better and it will be possible to perform the welding with adding filler metal into the arc if there is a diver-welder. A proper kind of carbon or graphite electrodes that will stand rapid changes of heat without disintegration should be chosen for under-water welding.

The experiments performed by the laboratory demonstrated the possibility of under-water electric arc welding under laboratory as well as practical conditions.

The following applications of under-water welding may be of practical interest:

1. Welding at a considerable depth in sea or fresh water performed by diver-welders. Under-water ship repair, lifting of sunk ships, repair and erecting of the under-water part of different hydrotechnical constructions, etc.

2. Welding at an insignificant depth, the welder working without a diving dress. Repair of damages of bodies of ships when the work is done inside the body.

3. Welding of details plunged into water on purpose. This method of welding differs essentially from the ordinary air welding. First, the influence of the atmospheric air upon the molten metal is eliminated. Second, owing to the intense cooling influence of the water upon the welding zone, the volume of the thermic influence zone diminishes and so do the shrinkage stresses and deformations. These peculiarities of under-water welding may be of great interest in special cases of welding.

Hereby we are summing up the results of our work:

1. A metallic and a carbon arc can burn stably enough in fresh and sea water at different depths.

2. It is fully possible to perform arc welding and cutting under water and to obtain good results.

3. A metallic arc burns stably enough and produces a normal deposit of metal only if special, coated electrodes are used. The coating of the electrodes for under-water welding may be of various chemical compositions, but two absolutely essential conditions must be provided.

(*a*) The layer of the coating must be thick enough.

(*b*) The coating must be watertight, which property can be acquired by varnishing the surface of the coating among other methods.

4. Best under-water welding results are obtained when the arc is fed by direct current.

5. The welder may not wear any diving dress when the work is being performed at an insignificant depth. The main difficulty in under-water welding is the bad visibility of the welding place.

The Effect of Heat Treatment of Welds

By **L. W. SCHUSTER**

THE Institution of Mechanical Engineers has issued the first report of the Welding Research Committee prepared by L. W. Schuster. From this report we are publishing the following passages which have been printed in *The Engineer*.

Object of the Research

The Committee has on its program a study of the various effects that heat treatment has on welded pressure vessels, and among these is the effect on the mechanical properties and the structure of the weld metal. It is realized that a study of this effect will be a complex matter on account of the large number of variables, such as:

1. The carbon and manganese content.
2. The quantity of any special elements present.
3. The amount of dissolved gases, especially oxygen and nitrogen.
4. The number of "runs" of metal and their depth.
5. The heat energy given by the arc to the metal, and the conditions governing deposition.
6. The plate thickness and size.
7. The difference in the rate of cooling of the metal during heat treatment.

On account of these variables and the lack of uniformity in the method adopted in preparing specimens, past results have led to much difference in opinion on the effect of heat treatment on the mechanical properties of welds, and it was considered that an immediate investigation to ascertain the effect was likely to lead to results apparently contradictory and difficult to analyze. To assist the separation of the variables and to allow of the interpretation of results with greater confidence it was decided that a preliminary investigation was first required, in which a series of specially prepared electrodes, with cores of graded composition and coverings that gradually reduced atmospheric contamination, should be used. The welds were to be designed specially and made under known conditions in plate of standard quality, and the tests were to be made on the individual runs of metal.

Such a preliminary investigation would be abnormally lengthy and costly if a full range of mechanical tests were employed, and great difficulty would be experienced in cutting out specimens of suitable size from the various runs of metal. The conclusion was, therefore, reached that for such a series of tests the Izod test, coupled with metallurgical examination, would probably give very useful information—that is, if results showed that this form of test could be relied upon to give consistent figures.

To test the suitability of the proposed procedure, it was decided to experiment first on a trial set of welds prepared with a single electrode, and the results obtained furnish the object of this report. The investigation is being continued and the scope extended to plates welded with the full range of electrodes.

Explanatory Note

In order to make clear the reason for the procedure adopted, the following points should perhaps be mentioned. A fusion weld is the result of the deposition of several runs of metal; the top run, being cooled from the molten state, has a comparatively coarse structure, and the whole or a large part of the lower runs being refined under ideal conditions, has, in general, an exceedingly fine structure. It is clear, therefore, that the effect of heat treatment may be very different at the various parts of a weld.

Design of Welded Plates

To separate the runs of metal, two methods of welding plates were adopted, a set of specimens being cut from each plate, away from the edges. The methods adopted were:

1. Form *A* designed to represent the coarse metal of the top run only.
2. Form *B* designed to represent the fine metal of the lower runs.

In addition, to ascertain whether the test figures from the top run of metal would change if the rate of cooling of the welded plate was retarded, the form *A* specimens were welded in two different manners:

(*a*) With the plate cold, as in normal practice at the commencement of welding.

(*b*) With the plate preheated, to represent a plate which has become very hot when welded.

Form of Izod Specimen

For current practice to be truly represented, the method of manufacture kept simple and the cost of welding kept low, an Izod specimen with a greater depth than about $^1/_4$ mm. was not feasible. The actual specimens adopted for trial were 10 mm. wide by 5 mm. deep, and the depth of notch, though otherwise standard, was 1 mm., the standard (120 ft.-lb.) Izod machine being used. Though the specimens are not standard, the results are obviously comparable with one another. A particular object of the tests was to establish whether:

1. Reasonably consistent results are given by similar specimens.
2. The particular form of specimen makes it possible to discriminate, with sufficient sensitiveness, between the various degrees of toughness that can be induced in a given weld.

Type of Electrode

For the trial series a high-grade covered electrode was used. It was covered with a heavy coating of iron oxide and silica in a proportion giving an acid slag, a half lap coating of white asbestos being used for convenience of manufacture. Among other ingredients the coating contained ferro-manganese for deoxidizing and adding manganese synthetically to the weld metal. The core was of the usual mild steel, containing about 0.12% of carbon and 0.5% of manganese.

Heat Treatment

Heat treatments were carried out at 600, 650 and 920° C. With the high-temperature treatment especially it was realized that the rate of cooling is a vital factor in affecting the structure of weld metal and the Izod results. For this reason, cooling was carried out at several different rates, which were kept strictly under control, under conditions that lent themselves to ready reproduction if required for future series of tests.

General Remarks on Quality of the Metal

The weld metal was remarkably clean and free from slag, and in only one instance was there evidence that an Izod result was affected by defective metal. In

general, only a few minute oxides were seen under the microscope. The high specific gravity of the weld metal, 7.87, gives evidence of the general soundness of the metal.

Analysis of Weld Metal

Analysis showed 0.020% of nitrogen and 0.078% of carbon, the drillings beng taken just away from one end of a weld. Though the nitrogen content is small, the micro-structures show that this lay partly in the pearlite. The manganese content varied between 0.24 and 0.32%. There was insufficient material available for further analysis but a similar weld described in an Appendix was free from molybdenum, chromium, nickel, titanium, vanadium, zirconium, xerium or uranium elements that might have been added synthetically from the covering of the electrode.

General Comment on the Consistency of the Izod Results

The consistency of the figures obtained from similar specimens is highly satisfactory; from all the sets of specimens treated any difference in result was of moment on two occasions only. The difference that then occurred would seem to be due to local variability in the quality of the metal. Be that as it may, the consistency of the results exceeded expectations, and the percentage variations were no more that have been found from tests on welds made with specimens of standard size.

Again, the sensitivity of the specimens is satisfactory, a ratio of 10 to 1 being obtained with the heat treatments adopted.

Even though shallow Izod specimens may be unsuitable in commercial steels with a comparatively large grain size and possibly comparatively large slag inclusions, this does not necessarily apply to weld metal (even to an outer run) that may be considered coarse for weld metal; weld metal has a considerably smaller grain size than that usually found in a mild steel forging, and the amount of included non-metallic matter when the weld is clean is smaller than that in the usual commercial steel. If, when a weld is tested, slag is visible at the surface of fracture, the test results would be valueless, and should, of course, be neglected.

Conclusions (Not Necessarily Applicable to Other Welds or Other Forms of Test)

1. The consistency of results representing similar specimens and the large difference between results given by dissimilar specimens testify that the form of specimen used was suitable for the purpose. No indication was given that the Izod test is other than suitable for showing changes that heat treatment may bring about in weld metal.

2. The shock value of the top run is considerably less than that of the lower runs.

3. The exceedingly good shock value obtainable in the bottom runs of a good quality weld metal is largely due to the very fine-grain structure induced when the weld is suitably made. Such a fine-grain size can be induced in the top run only by a form of treatment that cannot be carried out practically.

4. If the best results are to be given after a heat treatment at 900° C., the rate of cooling must be as rapid as possible. This applies to all the runs of metal, but especially to the top run. Although with a reduction in the rate of cooling, there is a falling off in the Izod value of a plain carbon steel, the reason is different when nitrogenous weld metal almost free from carbon has a lowered value. Not only with a slightly retarded rate of cooling does any nitrogenous pearlite, present in the austenitic or partially austenitic form, change to the pearlitic form and do needles come of solution in a supersaturated ferrite, but, with still slower rates of cooling, the nitrogenous pearlite is partially replaced by needles.

5. If the metal of the lower runs is heat treated above the upper critical range and the rate of cooling is sufficiently rapid, the original nuclei of the grains are not destroyed, and neither is the grain size increased nor the Izod value lowered. If, however, the rate of cooling is slow, the very fine initial grain size is increased and a falling off in the Izod value of the lower runs is expected from this cause alone.

6. A consideration of, say, a heat treatment in which the rate of cooling is of about the same order as that of a moderately heavy welded part cooled in air from 900%, shows that the Izod value of the top run improves markedly, but that the metal of the lower runs behaves in opposite fashion. The treatment might therefore well result in a fall in the value given by the usual composite weld in a $^1/_2$-in. plate. An advantage would, however, lie in the fact that the coarse metal of the top run, or of a backing run at the bottom, i.e., of either of the parts exposed to the greatest bending stress, will be made tougher by the treatment.

7. On the other hand, treatment in which the rate of cooling is quicker and corresponds with that of a small part, shows that the top run receives a greater benefit than that just described, and that the lower runs are not depreciated. The treatment is therefore of benefit in so far as the shock value is concerned. (A weld, consisting of three runs, made by a different operator with a similar electrode in a $^1/_2$-in. plate, gave 13.5 and 9 ft.-lb. when as received, and 56 and 60 ft.-lb. when normalized with a standard 10-mm. notch. Though the composition of the metal was not identical with that of the metal under review, and the results are for this reason not strictly comparative, they lend strong support to the conclusion just given.)

8. Where a joint is massive or the depth of the runs excessive, the bottom portion of one or more of the lower runs is, when welded, not necessarily refined to its full depth. It can be concluded, therefore, that a weld in such a part when heat treated at 900° C. has the residual coarse structure removed. For this reason, if the article were cooled at a slower rate, benefit might well be conferred upon the lower runs as well as the top run.

9. A mild heat treatment at 600° C. for one hour followed by a rate of cooling which is of the same order as that occurring when a moderately heavy welded part is cooled in air, has no effect on the shock value of either the top or the lower runs of this weld metal. Such a treatment would, however, be sufficiently drastic to remove an appreciable proportion of the internal stress in a part of medium size.

10. A prolonged heat treatment at 650° C., followed by a slow rate of cooling, causes a small loss in the Izod value of all the runs. It is to be concluded, therefore, that when a large article is given a low-temperature heat treatment to relieve stress there may be a small falling off in the Izod value of this particular weld metal, but that this will not be serious. The metal of an outer run will, however, remain as coarse as it was originally.

11. In the practical application of those conclusions it is to be borne in mind that with a higher nitrogen content the changes in structure may well be more marked than those shown by this weld. With quick rates of cooling there might be a greater tendency for the nitrogenous pearlite to be retained in the austenitic phase, and with rates of cooling not too quick, a greater tendency for needles to form.

Tensile Tests of Welded and Riveted Structural Members

By R. P. DAVIS *and* G. P. BOOMSLITER

✦Paper to be presented at Fall Meeting, A. W. S., Detroit, October 2nd to 6th, by R. P. Davis, Dean, and G. P. Boomsliter, West Virginia University. Contribution to Fundamental Research Committee, A. B. W.

Object of Investigation

THE object of this investigation was to determine the strength of tension members composed of angles with both welded and riveted joints. The effect of these two types of joints on the distribution of stress over the cross section of the member, especially at stresses below the elastic limit, was of particular interest.

The specimens tested included: single angles, two angles on same side of connecting plate, two angles with connecting plate between, two angles with two connecting plates and four angles with two connecting plates. These types are extensively used in structural work, the first three types, for example, being used in the bracing systems of truss bridges and the last two for lower chord sections. The detailed designs of these members are shown on Plates 1 and 2, while Figs. 4, 5, 6 and 7 illustrate half-tone views of the specimens after failure.

Acknowledgments

All specimens, including jaws and pins, were fabricated and furnished by the Fairmont Mining Machinery Company of Fairmont, West Virginia. Grateful acknowledgment is here made for their generous cooperation.

The testing was done by R. L. Fossnight, graduate student, and E. L. Harris, senior student, both in the civil engineering department. The photographs were made by Professor Lewis V. Carpenter.

Description of Specimens

The details of the riveted specimens are shown on Plate 1 and of the welded specimens on Plate 2. The size of angles in all cases was 3 x 3 x $^5/_{16}$ in. The distance center to center of pinholes was 3 ft. $8^1/_2$ in. A greater length would have been desirable in order to more closely conform to actual construction, but the limit of head room in the testing machine made this impossible.

In the riveted specimens the rivets were placed along the standard gage line, which for a 3-in. leg is $1^3/_4$ in.

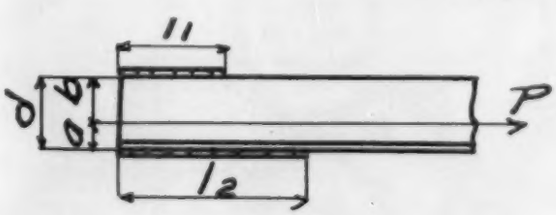


Fig. 1

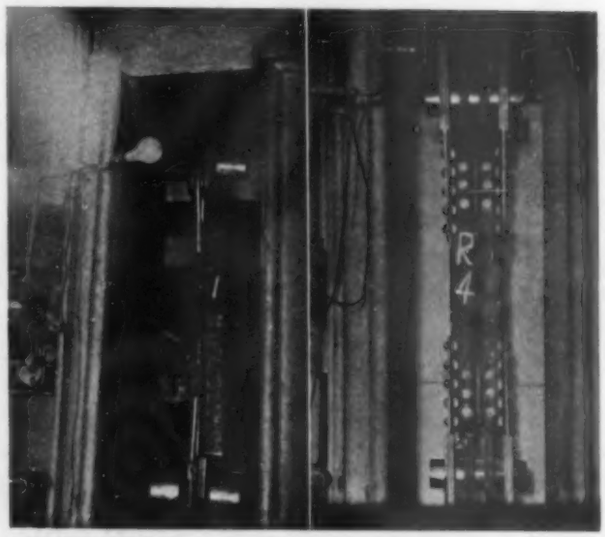


Fig. 2—W-1 in Position in Testing Machine

Fig. 3—R-4 in Position in Testing Machine

from the back of the angle. The number of rivets used in each joint was figured as in engineering practice, based on the following assumption: (1) that the effective area of a single-angle tension member or of each angle of a double-angle tension member, in which the angles are connected back to back on the same side of a gusset plate, is assumed as the net area of the connected leg plus half the area of the unconnected leg; and (2) that the effective area for double-angle tension members connected with the angles back to back on opposite sides of a single gusset plate and for angles connected with separate gusset plates, is assumed as the full net area of the angles.

Except in the case of the specimens composed of two angles on the same side of a single gusset plate, the load was applied, in the case of the riveted members, along the rivet line rather than along the gravity axis, since this conforms to current practice in riveted work.

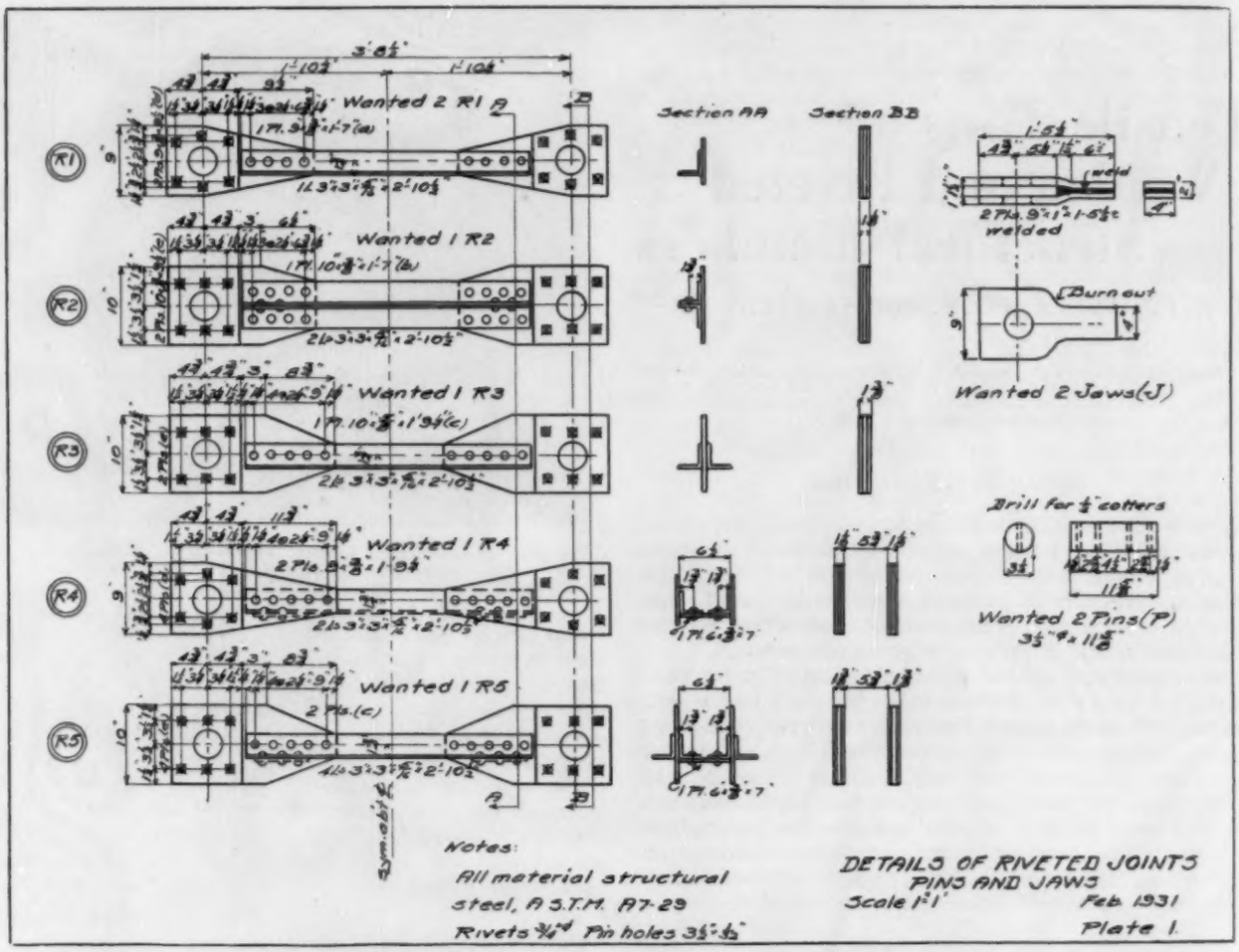
Six riveted specimens were tested, namely, R-1, R-1*A*, R-2, R-3, R-4 and R-5. Members R-1 and R-1*A* were identical, being composed of a single angle. Member R-2 was composed of two angles back to back and on the same side of the connecting plate, while R-3 was composed of two angles back to back and on opposite sides of the connecting plate. Members R-4 and R-5 were double-webbed specimens, R-4 having two angles inside the connecting plate and R-5 having four angles, two inside and two outside the plates.

The number of rivets used was based on unit shearing and bearing values of 12,000 and 24,000 lb. per sq. in., respectively, and an allowable unit tensile stress in the member of 16,000 lb. per sq. in.

On this basis the design strength of each angle of specimens R-1 and R-2 was 17,000 lb., the effective area being 1.065 sq. in., after deducting from the cross section one-half the area of the outstanding leg and also the cross-sectional area of a $^7/_8$ in. hole. The effective area of each angle of R-3, R-4 and R-5 was 1.51 sq. in., giving a carrying capacity for each angle of 24,000 lb.

In all cases shear governed the required number of rivets. Four rivets were required for R-1, 8 rivets for R-2, 5 rivets for R-3 and 10 rivets for R-4 and R-5.

The welded specimens differed from the riveted ones only in the type of connection. The welds were so designed that the center of gravity of the weld coincided approximately with the gravity axis of the member par-


Wanted 2 R1
Wanted 1 R2
Wanted 1 R3
Wanted 1 R4
Wanted 1 R5
Section AA
Section BB
Burn out
Wanted 2 Jaws (J)
Drill for ¼" cotters
Wanted 2 Pins (P)
Notes:
All material structural steel, A.S.T.M. A7-29
Rivets ¾" Pin holes 3½"
DETAILS OF RIVETED JOINTS
PINS AND JAWS
Scale 1"=1"
Feb 1931
Plate 1.

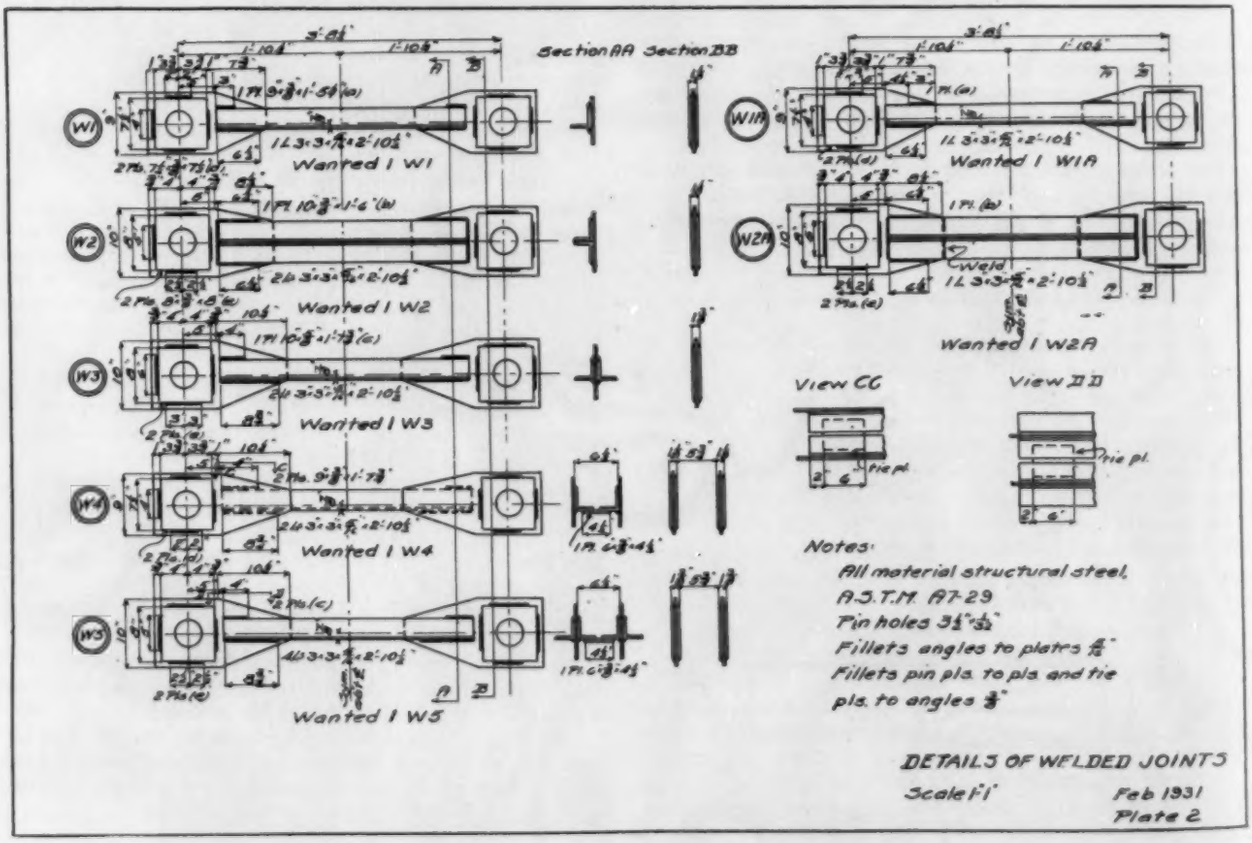

Section AA
Section BB
Wanted 1 W1
Wanted 1 W2
Wanted 1 W3
Wanted 1 W4
Wanted 1 W5
Wanted 1 W1A
Wanted 1 W2A
View CC
View DD
Notes:
All material structural steel, A.S.T.M. A7-29
Pin holes 3½"
Fillets angles to plates
Fillets pin pls. to pls. and tie pls. to angles
DETAILS OF WELDED JOINTS
Scale 1"
Feb 1931
Plate 2.

Fig. 4—Front View of Welded Specimens after Failure

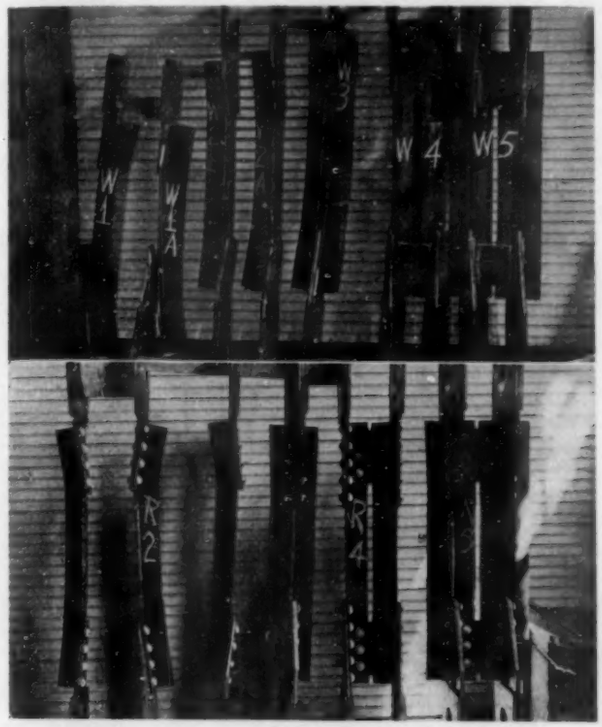


Fig. 5—Front View of Riveted Specimens after Failure

allel to the outstanding legs. The load was applied along this gravity axis.

In Fig. 1 let a equal distance from back of angle to gravity axis, d equal width of leg, l_1 equal length of weld along outer edge of leg, l_2 equal length of weld along back of leg and L equal total required length of weld; then to have the gravity axis of weld coincide with gravity axis of member,

$$l_2 = L(d-a)/d$$

and

$$l_1 = La/d$$

All welds of angles to plates were $^5/_{16}$ in. and were designed on the basis of 2500 lb. per lin. in. with a $^1/_4$-in. allowance at ends of welds.

Method of Testing Specimens

All specimens were tested in a 400,000-lb. capacity Olsen Universal machine. The jaws and pins used are detailed on Plate 1. Figures 2 and 3 show two specimens as they appeared in the testing machine. The jaws were wedged into the heads of the testing machine and the load was transmitted from these jaws into the specimens by means of pins extending through holes in the jaws and in the gusset plates.

In the case of those specimens composed of single angles or of two angles on the same side of gusset plate, the test pieces were so placed that the load was applied along the back of the angles.

In order to study the elastic behavior of the specimens $^1/_{64}$-in. strain-gage holes were placed 10 in. apart so that a point half way between these holes coincided with the center of the length of the specimen. A Whittemore strain gage was used to measure deformations, these measurements being taken at three points on each angle, one near the junction of the two legs and one near the extremity of each leg.

An initial load was applied to tighten the grips, after which the first strain gage readings were taken. Increments of load were placed on the specimens and readings taken until the yield point was reached, after which the specimens were tested to failure. The load-strain curves are shown on Plates 3, 4 and 5, inclusive.

Results of Tests

Specimen W-1. See Plates 2 and 3 and Figs. 2, 4 and 6.

This type is a single angle with welded joints. The ultimate load was 72,470 lb. Failure was due to tension in the weld, caused by the large distortion resulting from eccentricity of load application.

Due to the eccentricity of applied load the stress was very unevenly distributed over the cross section of the angle. A part of the outstanding leg was in compression up to and probably somewhat beyond the elastic limit. (See Plate 3.)

Specimen W-1*A*. See Plates 2 and 3 and Figs. 4 and 6.

This type is the same as W-1. The ultimate load was 67,400 lb. In order to see if the strength of the type W-1 could be increased by changing the position of the short weld, in W-1*A* the short length of fillet weld was placed near the end of the gusset plate instead of near the end of the angle. Due to an error in fabrication only one end was made as desired, the weld on the other end being made $6^1/_2$ in. in length along each bead.

Failure was similar to that of W-1, occurring at the end with the shorter length of weld.

Specimen R-1. See Plates 1 and 3 and Figs. 5 and 7.

This type is a single angle with riveted joints. The ultimate load was 60,600 lb. Failure was through the rivet hole nearest the end of gusset plate.

The distribution of load over the cross section of the angle was similar to that of W-1, except that the increase of strain with load increment was not as uniform.

Specimen R-1*A*. See Plates 1 and 3 and Figs. 5 and 7.

This was the same type as R-1. The ultimate load was 64,100 lb. The character of failure was the same as that of R-1. The deformation diagram (Plate 3) is also quite similar to that for R-1 (Plate 3).

Specimen W-2. See Plate 2 and Figs. 4 and 6.

This type is composed of two angles back to back, welded to the same side of gusset plate. The ultimate load was 101,500 lb.

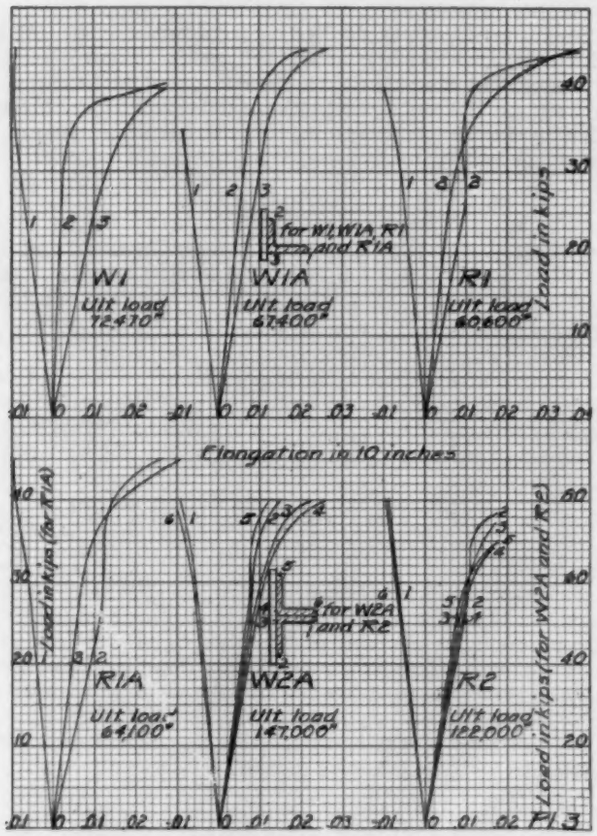
As shown in Fig. 6, failure resulted by the weld failing along the end of the angles. This is a poor type of member when using a welded joint because, owing to the impossibility of welding both sides of the angle, the gravity axis of the weld cannot be made to coincide with the gravity axis of the angle. This results in a twisting action, which is clearly shown by the tendency of the two angles to separate.

The effect of this eccentricity is not so marked at loads below the elastic limit. This is probably due to the end weld taking most of the load. The ultimate load would doubtless have been considerably increased if the outstanding legs of the two angles had been connected by spot welding.

Specimen W-2*A*. See Plates 2 and 3 and Figs. 5 and 7.

This type is similar to W-2, except that a weld was placed connecting the end of the gusset plate to the back face of one leg of each angle. It was thought that this weld acting with the one parallel to it at the end of the angle would create a resisting couple to offset the moment due to eccentricity.

Plate 3



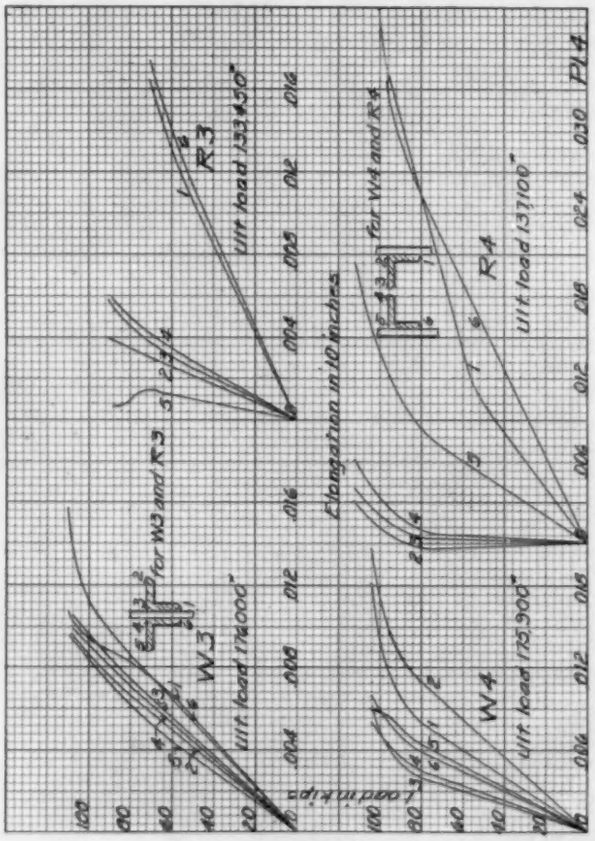


Plate 4

The ultimate load was 147,000 lb., nearly fifty per cent increase over the strength of W-2, which indicates the correctness of this assumption. Failure was in the weld along the back edge of the angle.

Specimen R-2. See Plates 1 and 3 and Figs. 5 and 7.

This type is composed of two angles back to back, riveted on the same side of gusset plate. The ultimate load was 122,000 lb., failure resulting from a break in the angles through the rivet holes nearest the end of gusset plate (Fig. 7).

The elastic deformation of the fibers is quite similar to that of the welded specimens, in all cases the outstanding legs being in compression. The stress in the riveted legs seemed to be uniformly distributed.

Specimen W-3. See Plates 2 and 4 and Figs. 4 and 6.

This type is composed of two angles back to back, welded on opposite sides of the gusset plate. The ultimate load was 176,000 lb., failure being in the angles, as shown in Figs. 4 and 6. It is of interest to note the small twisting of the member as compared with specimens W-1, R-1, W-2 and R-2, due to the absence of load eccentricity.

As shown in Plate 4, the stress distribution was quite uniform. As would be expected the stress at the outer fibers of the outstanding leg is slightly less than in the other leg.

Specimen R-3. See Plates 1 and 4 and Figs. 5 and 7.

This type is composed of two angles back to back, riveted on opposite sides of the gusset plate. The ultimate load was 133,450 lb., failure resulting from a break in one angle through the rivet hole nearest the end of the gusset plate, as shown in Fig. 7.

The effect of the rivet gage line being off the gravity axis parallel to the outstanding leg is clearly shown on Plate 4, the strain of the fibers along the outside edge of the connected legs being over four times the strain in the outstanding legs. The eccentricity of applied load was 1.75–0.89 = 0.86 in.

The superiority within the elastic limit of the welded connection (Plate 4) is very apparent. For example, with a load of 60,000 lb. the maximum strain for the riveted connection was more than twice that for the welded connection. The same ratio, however, will not obtain for the ultimate strength, since there is a pronounced tendency near the ultimate load for the specimen to distort in such a manner as will lead to a reduction in the eccentricity.

Specimen W-4. See Plates 1 and 4 and Figs. 4 and 6.

This type is composed of two angles welded to two gusset plates. The ultimate load was 175,900 lb., failure being in the angles as shown in Figs. 4 and 6. The small amount of bending of the specimen at failure is to be noted.

In this type of member the stress should be rather uniformly distributed over the cross section, since there is no eccentricity of load with respect to the member as a whole. On Plate 4 there is shown a considerable variation of stress. On one angle (containing points 4, 5 and 6), the stress is fairly uniform; but on the other (containing points 1, 2 and 3), the stress is quite variable.

Specimen R-4. See Plates 2 and 4 and Figs. 3, 5 and 7.

This type is composed of two angles riveted to two gusset plates. The ultimate load was 137,100 lb., failure resulting from a break in one angle through a rivet hole nearest the end of a gusset plate.

As shown on Plate 4, the stress within the elastic limit was very unevenly distributed. Owing to the load application of rivets being off the gravity axis parallel to the outstanding legs, points 1 and 6 are much more heavily stressed than other points on the cross section. Compared with W-4 (see Plate 4), the maximum strain for the same load is more than twice as much.

Why point 5 should have considerable stress while points 2, 3 and 4 are without stress is hard to explain.

Specimen W-5. See Plates 2 and 3 and Figs. 4 and 6.

This type is composed of four angles welded to two gusset plates. The maximum load carried was 327,000 lb., but this did not represent the ultimate strength of the specimen, because one of the jaws broke at the above noted load, making it impossible to carry the test to the point of failure of the member.

By looking at Plate 5, it will be noted that the fiber deformations within the elastic limit are not as uniform as might be expected considering the fact that there is no load eccentricity. It is to be expected that points 5 and 12 would be stressed slightly less than those fibers along the attached leg. It is also reasonable to expect that points 8 and 9 would have somewhat less stress, although more than the fibers at points 5 and 12. These expectations are borne out by the tests. Why points 3 and 4 should be more heavily stressed than points 1 and 2 is hard to explain, except that there was a slight eccentricity in the pinholes. However, it was observed that in most of the tests with two gusset plates the load was not equally distributed to the two plates.

Specimen R-5. See Plates 1 and 5 and Figs. 5 and 7.

This type is composed of four angles riveted to two gusset plates. The ultimate load was 278,900 lb., failure resulting from a break in one of the angles through a rivet hole nearest the end of a gusset plate.

As shown on Plate 5, the stress within the elastic limit was unevenly distributed. Owing to the line of rivets and load application being off the gravity axis of the angles, points 1, 2, 3 and 4 were much more heavily stressed than the other points. Compared with W-5 (Plate 5), the maximum strain at equal loads is more than twice as much.

As would be expected, points 5 and 12 have the least stress, followed by points 8 and 9. In this test the load seems to have been well distributed between the two gusset plates.

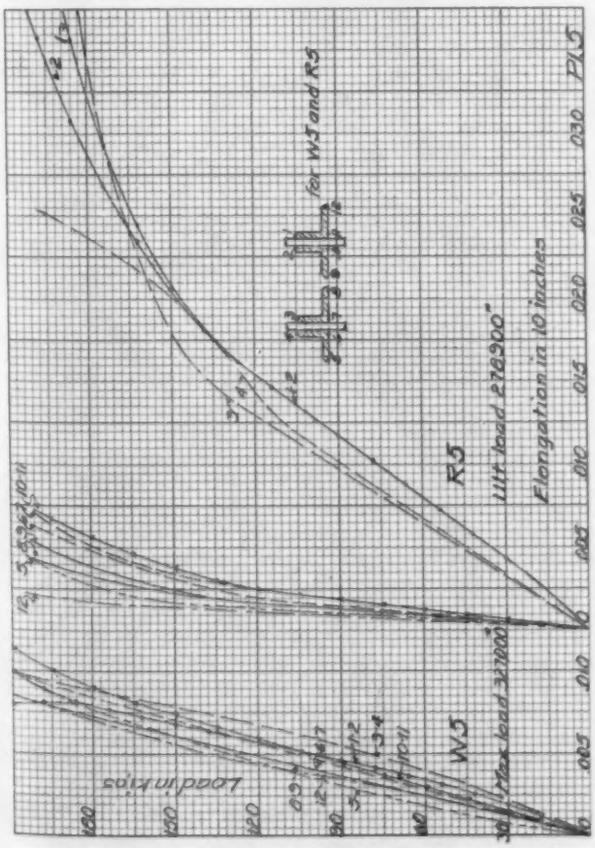


Fig. 6—Side View of Welded Specimens after Failure

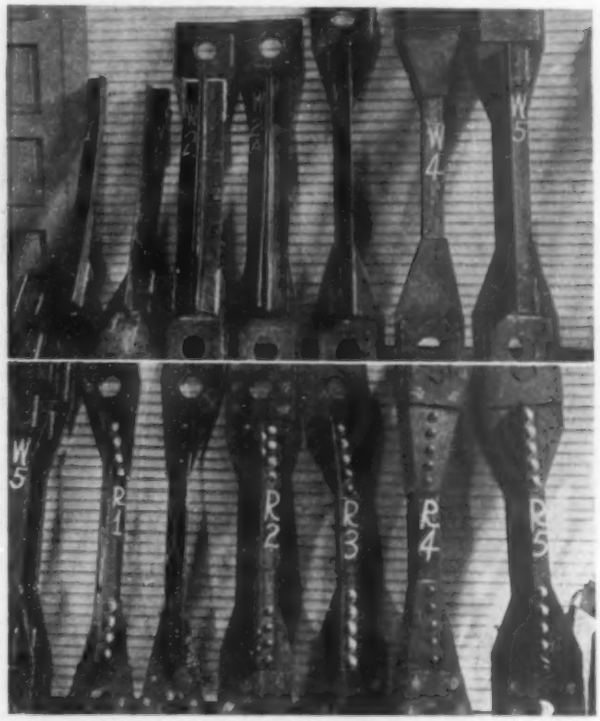


Fig. 7—Side View of Riveted Specimens after Failure

Discussion of Results

In comparing welded *vs.* riveted connections the discussion will be divided between results at ultimate loads and results within the elastic limit.

Ultimate Loads.—Table 1 summarizes the ultimate load results.

Although members W-1, W-1A, W-2 and W-2A failed in the weld, it is probable that the ultimate loads represent, except in the case of W-2, very nearly the ultimate capacity of the angles. At the time of failure the specimens were badly distorted and were elongating rapidly without increase of load, indicating an approaching failure. It is believed that stronger welds would not have materially increased the strength of the specimens. The excessive distortion (see Figs. 4 and 6), due to this elongation and to eccentricity of load application, resulted in an abnormal type of failure.

As stated elsewhere the low load value for W-2 was due to the large eccentricity of the weld on the two individual angles.

In column 9 there is given the ultimate unit stress on the cross section based on a rivet hole deduction. On this basis there is not a great amount of difference between the unit strength of the welded members and the riveted members, the welded members being stronger just about in proportion to the larger area of cross section by virtue of no deduction for riveted holes.

Members W-3 and W-4 and probably W-5 are somewhat stronger than R-3, R-4 and R-5, respectively, even when the comparison is made on the basis of net section. This is probably due to the eccentricity of load application for the riveted members, since this load application is 0.86 in. from the gravity axis parallel to the outstand-

Table 1

1	2	3	4	5	6	7	8	9	10
Member	Ultimate Load, Lb.	Ultimate Load, Lb. per Sq. In.	Efficiency, Per Cent	Member	Ultimate Load, Lb.	Ultimate Load, Lb. per Sq. In. Gross Section	Efficiency	Ultimate Load, Lb. per Sq. In. Net Section	Efficiency, Per Cent
W-1	72,470*	40,700*	71	R-1	60,600	34,000	60	40,200	70
W-1A	67,400*	37,800*	66	R-1A	64,100	35,900	63	42,400	74
W-2	101,500*	28,500*	50						
W-2A	147,000*	41,200*	72	R-2	122,000	34,200	60	40,400	71
W-3	176,000	49,500	87	R-3	133,450	37,500	66	44,200	77
W-4	175,900	49,500	87	R-4	137,100	38,500	68	45,400	79
W-5	327,000†	46,000†	80	R-5	278,900	39,200	69	46,200	81

* Failed in weld
† Not breaking load

ing legs. The same eccentricity is present in members R-1, R-1A and R-2, but for these members the eccentricity about the axis parallel to the connected leg is such as to largely obscure its effect.

Tests of the metal indicated the ultimate strength of the steel to be 57,200 lb. per sq. in. The efficiencies as given in Columns 4, 8 and 10 are based on this figure.

Elastic Limit Values

Referring to Plates 3 and 5, inclusive, it is seen that the load strain diagram for the most stressed fiber ceases to be a straight line at a deformation point of 0.01 in. in ten in., or a little higher, corresponding to a stress of 30,000 lb. per sq. in., or a little more, evidently the elastic limit of the material.

For W-1 this occurs at a load of 25,000 lb., for W-1*A*, 30,000 lb., for R-1, 25,000 lb., for R-1*A*, 25,000 lb., for W-2*A*, 60,000 lb. and for R-2, 57,000 lb.

Assuming the elastic limit of the steel to be 30,000 lb. per sq. in. and the stress to be uniformly distributed, the load capacities at elastic limit would be as follows: W-1, W-1*A*, R-1, R-1*A*, 53,400 lb.; W-2, W-2*A*, R-2, 106,800 lb. Dividing the actual loads carried at elastic limit by these theoretical loads, we get the following percentage efficiencies: W-1, 47, W-1*A*, 56, R-1, 47, R-1*A*, 47, W-2*A*, 56, and R-2, 53.

In other words, for the types of sections tested, the effective area is equal to the area of the connected leg only.

On Plate 3 the elastic deformation of the fiber at point 2 of R-1 is peculiar in that it elongates as a straight line up a load of 25,000 lb., after which there is no additional elongation for a considerable increase of load. The same phenomenon is observed on Plate 3 for R-2. This is probably due to rivet slip. It will be observed that in the case of R-1 and R-1*A* the fibers at point 2 elongate the most, whereas in the case of W-1 and W-1*A* (Plate 3), the greatest deformations occur on fibers at point 2. This difference is due to the fact that for R-1 and R-1*A* the load is eccentrically applied with reference to the gravity axis parallel to the outstanding leg.

On Plate 3 for specimens W-2*A* and R-2, respectively, the effect of symmetry about the axis parallel to the outstanding leg is clearly shown. Here the fibers at points 2, 3, 4 and 5 have nearly the same tensile stress, while fibers at points 1 and 6 have nearly equal intensities of compression stress.

On Plate 4 is shown the deformation curves for W-3. Here the stress is fairly well distributed over the cross section. At the elastic limit the load is 92,000 lb. For an assumed elastic limit of 30,000 lb. per sq. in. and a uniform distribution of stress the theoretical load capacity at elastic limit is 107,000 lb. Thus, the efficiency is 86 per cent. Hence, the effective area may be taken as the area of the connected leg plus approximately one-half the area of the unconnected leg.

The riveted specimen R-3, which is of the same type of section as W-3, does not show nearly as satisfactory a distribution of stress as may be seen on Plate 4. This is probably due to load eccentricity causing much larger fiber elongations at points 1 and 6 than at other points. However, here a new phenomenon is presented. The load-deformation curves continue as essentially straight lines far beyond the deformation point representing the elastic limit for the specimens previously discussed.

On the assumption that the 60,000-lb. load represents the point at which the maximum intensity stress reaches the elastic limit, the type of section represented by R-3, using standard rivet-gage line as the load application line, R-3 is no stronger than R-2, which was shown to have an effective area of cross section equal to the area of one leg only.

Owing to the small length of specimens, the elastic curves for W-4, W-5, R-4 and R-5 may not be typical of full-size members. Where the length of the member is small, for double-web specimens the inaccuracies of fabrication may amount to a considerable percentage of the elastic lengthening of the fibers, thus introducing large percentage errors; whereas, in full-sized members the inaccuracies are no larger than for short members and so, when expressed in terms of the total of the elastic deformations, are small.

For example, for W-4 were the load equally distributed to the two gusset plates the elongation at point 2 would be equal to that of point 5, yet the former is twice the latter.

Specimen W-4 (see Plate 4) has a much better stress distribution than R-4 (see Plate 4). In the case of W-4 the elastic limit appears to be reached at a load of about 80,000 lb. Using the same method of analysis as for the previous cases we find an efficiency of 75 per cent.

In the case of W-5 (see Plate 5), if the elastic limit is taken at an elongation of 0.01 in. in 10 in., the load is 190,000 lb. This results in an efficiency of 89 per cent.

Any attempt to make deductions from the results on R-4, shown on Plate 4, is more or less speculative. However, the elastic limit is perhaps reached at 64,000 lb. With this figure the efficiency is 60 per cent.

In the case of R-5 (see Plate 5) the elastic limit appears to be reached at a load of 140,000 lb., which results in an efficiency of 65 per cent.

The following table summarizes the efficiencies of the various sections as given in the foregoing discussion:

Member	Percentage Efficiency Based on the Elastic Limit	Member	Percentage Efficiency Based on the Elastic Limit
W-1	47	R-1	47
W-1*A*	56	R-1*A*	47
W-2*A*	56	R-2	53
W-3	86	R-3	56
W-4	75	R-4	60
W-5	89	R-5	65

Conclusions

The following conclusions are necessarily subject to a number of qualifications and should only be read after a careful study of the foregoing report.

1. In tension members composed of small angles the stress is not as uniformly distributed as generally assumed in specifications.

2. In tension members composed of a single angle or of two angles on the same side of the connecting plate the ultimate strength of the member per square inch of *net* section is about the same for both welded and riveted end connections. Based on the gross section the welded member is stronger because of the greater effective area.

3. In tension members composed of a single angle or of two angles on the same side of the connecting plate, the ultimate unit strength, whether welded or riveted, is about two-thirds to three-quarters the unit strength of the steel composing the section.

4. In tension members composed of two angles on opposite sides of the connecting plate, or of two angles with two connecting plates, or of four angles and two connecting plates arranged as in these tests, welded joints result in higher ultimate loads in pounds per square inch of net section than do riveted joints.

With welded joints the unit strength is about 85 per cent and with riveted joints about 78 per cent, based on the net section, and 68 per cent, based on the gross section, of the unit strength of the steel.

5. In tension members composed of a single angle or two angles on the same side of the connecting plate the elastic limit strength of the member is about the same for both welded and riveted connections. This is about one-half the elastic strength of the steel.

6. In tension members composed of shapes as listed under (4) in these conclusions, the elastic limit strength where riveted connections are used is about 60 per cent of the elastic limit strength of the steel.

7. In tension members composed of shapes as listed under (4) of these conclusions, the elastic strength where welded connections are used is from 75 to 90 per cent of the elastic unit strength of the steel.

Successful Manganese Steel Welding

By **E. L. QUINN**

†Paper read at March 23rd Meeting of Chicago Section, A. W. S., by E. L. Quinn, Welding Engineer, American Manganese Steel Company.

IT IS understood that discovery of manganese steel, "the toughest of known steels," resulted in an unusual way. Robert A. Hadfield, a young man, was assisting his father in the management of his steel works in Sheffield, England, in 1882. He wished to produce a steel that would possess both hardness and toughness, a seemingly very difficult combination to bring about. Hardness usually implies brittleness and toughness means softness in ordinary metals, and for the purposes for which tough hard steel is required no steel known at that time or discovered since gives such a combination or meets such requirements as manganese steel.

Hadfield's experiments began with the immediate object of learning how the properties of iron and steel could be modified by additions of other metals, and he commenced with the little-known metal manganese. Beyond small percentages of elements other than carbon, little was known about alloy steels. The chief one of importance was Mushet's self-hardening tool steel which had been produced and used in a limited way. However, it was even then known that manganese in small amounts, say, one or two per cent, was beneficial to steel, particularly in forging processes. It was also known that when the percentage reached three or four the ductility of the steel disappeared, and a brittle, worthless product resulted. There seemed, therefore, little grounds for further experiment.

However, Hadfield persisted, and in his first experiment on September 7, 1882, the amount of manganese added was from 10 to 14 per cent, or three or four times the quantity previously tried out. The result was a most remarkable metal and the forerunner of our present manganese steel.

It was found that ingots containing 3 to 4 per cent manganese when forged gave a brittle compound as expected; but in the case of 10 to 12 per cent, the material was quite hard and yet comparatively tough, bending considerably in the forged bar. On the 3 to 4 per cent material, the water-quenching when tried did not change its brittleness, while the bars of 10 to 12 per cent, quenched from a high temperature, bent double, cold.

Hadfield was puzzled by this result and at first thought that the bars had become reversed, but chemical analysis showed that no mistake had been made. Therefore, the remarkable fact was at once outstanding that a new material had been discovered, known as manganese steel. Much work, however, remained to be done before practical applications of the steel could be made. The metal manganese was expensive. The very qualities themselves of manganese steel presented difficulties. Steel, in general, can be cast and forged easily and finished to the proper size and shape by machining. While manganese steel can be successfully cast, in spite of difficulties not met with ordinary steel, it is more difficult to forge or roll; and machining by the usual methods is still not economical. These and other problems were patiently investigated and finally solved, so that today manganese steel is cast, forged, rolled, drawn and machined.

Machining, however, requires the use of special equipment, tools and technique.

The original castings of manganese steel as made by Hadfield were exhibited before the British Institution of Civil Engineers in 1887. The first commercial use of manganese steel was in pins for dredge buckets forged from ingots in 1889 or 1890 in Sheffield.

An exhibit by Hadfield in 1892 of such castings as wheels, shafts, chain links, plates and so on, shows that at that time, although on a small scale, the manufacture of manganese steel in England had become established.

The first manganese steel castings in America were made in 1892, and since then the production has grown from a small tonnage of light castings to a yearly total of perhaps 100,000 tons of castings, forgings and rolled products combined, ranging in size from a chain pin, weighing a few ounces, to dredge tumblers, pump shells and crusher heads, weighing as much as 30,000 lb. each.

The United States Army Ordnance Department's requirements as to analysis are:

Carbon	1.00 to 1.40%
Manganese	10.00 to 14.00%
Phosphorus...maximum...	0.10%

With this is required a heat treatment consisting of furnace heating to a temperature of about 1832 deg., followed by a water quench. Generally speaking, this analysis and treatment produce good manganese steel, and with no closer specifications than these, the physical properties will be about as follows, these figures representing an average of nineteen tests conducted a number of years ago by commercial laboratories of our cast and heat-treated bars.

Tensile strength	108,460 lb.
Yield point	53,396 lb.
Elongation	33.71%
Reduction of area	38.56%

Naturally, greater knowledge and experience over the years have been instrumental in determining specifications as to composition and manufacture that result in great improvement in physical characteristics over those obtainable within the rather wide range of chemical content suggested above.

When manganese, carbon and other elements are present in correct proportions, the average physical properties of cast manganese steel should be about as follows:

Tensile strenth	125,000 lb.
Yield point	50,000 lb.
Elongation	45%
Reduction in area	40%
Brinell hardness	185 to 200 increasing to a maximum under cold-working of 550 on the working face of the casting.

Manganese steel, while brittle in the cast state, after heat treatment and quenching, is in the austenitic state, which implies that the carbides are retained in solid solution. This gives the great toughness and the wear and shock-resisting properties for which this steel is noted above all others. The surface hardness at first is rather low, but the steel work-hardens rapidly and to a high degree, hereby acquiring a very hard surface (with ductile backing) that is maintained continuously with progressive wear. In one sense, the yield point is rather low, but, as the steel starts to stretch under stress, it immediately stiffens up rapidly. This increase in yield point is progressive almost to the ultimate strength of the steel, under repeated strain. The ability to build up a self-renewing hardness on the surface accounts for the extreme wear-resistance of manganese steel, while the presence of a tough ductile backing explains its resistance to shock.

An instance of the value of the ductility or moderate flowing tendency in manganese steel is in its use for sheaves or pulleys operated by wire rope. The sheave groove, instead of breaking off in tiny splinters under pressure and wear, as is the case with other metals, takes on instead a glass-like polish. This means that the groove wears out more slowly and there are no metal particles to imbed themselves between the rope strands to cut them away. Wire rope used with manganese sheaves will last, conservatively, 25 per cent longer than with ordinary pulleys.

Manganese steel, however, is not everlasting, and repeated impact and abrasion will eventually wear the metal away, and likewise, overload and fatigue are occasionally responsible for fractures.

In the not so distant past, the welding of manganese steel was looked upon with skepticism, and justly so, as the percentage of failures overbalanced the successful applications by a very large majority.

It has been pointed out that the value of manganese steel is due primarily to its very great toughness and resistance to abrasion; however, these qualities are developed only as a result of heat treatment and quenching, inasmuch as the alloy, when heated and allowed to cool slowly, is so extremely brittle and weak as to be of little value. This peculiar property has rendered it difficult heretofore to weld broken manganese castings successfully.

If common steel is used as a welding agent, the added material is deficient in tensile strength, ductility and wear resistance. If manganese steel welding rod of the conventional analysis is used, the result is usually worse in most respects, as the slow cooling of the added metal causes a partial transformation of the internal structure, making it so brittle that it often breaks due to cooling strains, and always under load or shock. Furthermore, the parent metal adjacent to the weld area usually undergoes the same transformation as the weld proper.

The foregoing facts were recognized by the largest producer of manganese steel castings, and resulted in extensive research to develop a welding rod that would successfully weld manganese steel and at the same time possess the inherent qualities of heat-treated manganese steel.

It was discovered that if $4^1/_2$ to 5% of nickel were added to the conventional manganese steel analysis, the difficulties encountered in welding could be wholly overcome owing to the fact that nickel, when present in these amounts, retards the phase transformation and prevents embrittlement on slow cooling by retaining the carbides in solution. This enables the production, even by comparatively unskilled workmen, of a weld which is equal to the parent metal in tensile strength, ductility, ability to work-harden under impact and abrasion resistance.

Periodical tests have indicated that strength welds made on 12–14% manganese steel with our coated nickel manganese welding rod will consistently give the following values:

Tensile strength —	105,000 lb. per sq. in.
Elongation	30%
Cold bend	90°

Recently a $2^1/_2$-yard manganese steel bucket, which for the past eight years was subjected to extremely

severe dredging operation, was used in an attempt to remove a concrete pier that had not been satisfactorily disintegrated by blasting. This undue stress resulted in a total of 45 in. of crack developing in the front of the bucket.

An order was immediately placed for a new bucket that would require about ten days for delivery; however, being a penalty job, it was desirable that the damaged bucket be repaired and returned to service as soon as possible. Welding operations were started on Saturday morning and completed Sunday morning, requiring a total of twenty-six (26) hours, including preparation. The bucket was returned to service and operated efficiently until delivery of the new bucket was obtained, at which time it was discovered that additional cracks had developed. However, they were far enough removed from the original welds to disclaim welding temperature as their cause.

The following procedure was employed in making the foregoing weld and is also applicable when welding carbon steel to manganese steel:

1. If the crack does not actually terminate in one of the rivets holes, a hole should be burned through the front where the crack does terminate, so as to prevent its further propagation.
2. The fracture should first be prepared to receive the weld metal by creating with the cutting torch a single V all the way through, the top width of which should not exceed the thickness of the metal section being welded. After this V has been cut, it should be thoroughly cleaned of scale, oxide and dirt by means of a grinding wheel and wire brush.
3. Apply the rod with reverse polarity using 110 amp. for $^5/_{32}$ in. and 130 amp. for $^3/_{16}$ in., having reference, of course, to the coated rods recommended for this type of welding. However, the condition of the meters and welding equipment may necessitate a change in this, and the welder can easily determine the most efficient welding heat to employ, bearing in mind that the minimum heat should be used that will give good fusion.
4. The back-step method of welding is recommended and each step should not be more than 2 in. in length. It is essential that each bead or layer of metal be thoroughly peened immediately on depositing and that each step should be completed to the full height of the V before starting the next step.
5. A reinforcement weld is permissible on the reverse side of the casting. This also should be thoroughly peened after welding is completed on the open V side.
6. As an aid to determining that the welding heat is being kept to a minimum, it should be possible to place one's hand on the part at least 6 in. from the weld at any time during the procedure.
7. Quenching is not necessary in using the welding rod and, in fact, should be avoided because of possible damage to the parent metal.
8. Of course, it is important to keep the welded beads clean by wire brushing at all times.

Great economy can be effected throughout the steel industry by utilizing nickel manganese steel welding rods to build up to their original dimensions carbon steel, as well as manganese steel parts, that have been made useless owing to impact or abrasion. As regards carbon steel, it is possible to obtain the desirable properties of manganese steel on the working areas, by merely building up, with nickel manganese welding rods, the relatively inexpensive carbon steel parts such as coupling boxes, wabblers, crabs, table gears, etc.

It may be well to point out that the building-up operation can be made less expensive by welding to slightly higher than the required dimensions and peening with an air or hand hammer to the required shape or size. This procedure serves two purposes, in that in many instances it eliminates expensive machining, and also work-hardens the nickel manganese weld metal, thus enabling it to resist initial service impact and abrasion more effectively.

Nickel manganese welding rod plays a very important part in track work maintenance, as the application of this material is especially adaptable to either manganese or carbon steel. Many of the large railroads, as well as traction lines have, after exhaustive tests, established welding departments that specialize in this phase of reclamation.

Instances can be pointed out where frogs and crossings that have been built up as much as $1^1/_4$ in., after two years service under heavy steel plant traffic, showed less than $^1/_4$-in. depression. The track work referred to was built up in place without any interruption of service, employing the following procedure:

1. The casting to be welded should be ground to remove all cracks, oxides and other imperfections detrimental to good welding practice. In fact, a casting that has been in service, even though it shows no surface defects, should be ground down somewhat to get beneath the work-hardened surface which, of course, is of a different metal structure than the original.
2. The proper welding current to be used should be determined by testing on a part other than that which is being welded. The minimum current at which the electrode will flow and produce satisfactory penetration should always be used.
3. The surface to be built up should be divided into sections of approximately $1^1/_2$ in. square, and the amount of metal deposited at one time should be confined to this area. The deposited metal, while it still shows color, should be peened with an air hammer, starting at the point where the arc was broken and working back. The deposit should be hammered smooth, but it is important not to do this peening to excess—that is, to the point where the metal starts to flake, indicating that the deposit has reached the point of brittleness.
4. The concentration of welding at one point on the casting tends to overheat it, and this excessive localized heat may have the effect of making the casting brittle. This can be avoided by distributing the pads of weld metal over the entire surface being welded, and also by changing from one casting to another from time to time.
5. It is suggested that the second layer of weld metal be applied at right angles to the first layer.
6. The weld metal should be kept clean at all times by the use of a wire brush.
7. Cold shuts on the edges and thin sections of the part being welded can be avoided by using a smaller diameter rod.

In closing, it may be well to state that the field for manganese steel is practically unlimited, and, in recognition of this, our company maintains a technical and engineering staff, as well as a modern physical and chemical laboratory, and will gladly cooperate with those having problems involving the use of manganese steel and the welding thereof. Supplementing this, the installation of a complete X-ray laboratory in the near future will permit the closest supervision and investigation of foundry and welding techniques.

Peening or Caulking

By C. J. HOLSLAG

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THE usefulness of peening, hammering and caulking is at last becoming known.

Hammer annealing for Class 1 pressure vessels or pipe work or for any structural work requiring absence of contracting stresses is becoming generally known and practiced. This process consists of forcing the deposited metal, layer by layer, by hammering so it occupies the space that was arranged for it to fill. In other words, the weld metal put in at a high temperature contracts and would either draw the welded pieces together or stretch itself. Hammer annealing corrects this besides holding the original alignment and it also closes pores and makes the metal denser by the same methods used in forging blooms and rolling billets.

In the early stages of welding in the United States peening with arc welding was used extensively but for a great many years thereafter it sort of fell into disuse because of a lack of understanding of its valuable properties. For instance, all the old-time boiler workers and such manufacturers that used arc welding in boiler work know that stress-relief was obtained by caulking a weld and that better results could be had both as to removal of stresses and grain refinement by peening the metal together with layer deposits in a V'd-out section. An old boilermaker trick in welding was the rattling of the metal by a bobbing tool or similar means so that in the welding of a patch its cracking would be prevented. This old use, recognized now as grain refinement and stress-relief, has again become important in the welding of heavy sections such as steam boilers, air pressure vessels, oil refining equipment, etc., and a résumé of the best methods for using this method is not out of place although the system described will be "old" reading to many.

Chipping is also very useful in cleaning welding. In fact, indispensable cleanliness is ahead of godliness in welding. For instance, in double grooved welds, the metal must be chipped from the opposite side before depositing the new first layer. Also, chipping of the slag or uneven portions of the weld of each finished layer is done among all firms who use the best method and they always used chipping for cleaning.

A method of cutting which replaces chipping is the use of metal electrode with heavier current and this method is also used to anneal the weld deposit and adjacent parent zone without changing the grain structure of the parent metal.

The ordinary boiler chipping hammer is the best tool and a dull chisel can be used although special ground tools shaped to fit the surface are better but not necessary. Air pressure hand caulking can be used too but an air hammer is better by far. Rather medium hard but not "forcing" blows should be used and in peening a weld, the same as caulking a riveted seam, a great deal of judgment must be used. For instance, if metal is actually forced down into cavities and imperfections closed by this method, there is more harm than good done. The idea of peening is to relieve effects of contraction of the weld metal by these means:

1. Forcing of the deposit to fill the original space and maintain the gap or vee dimensions.
2. Stress-relief by grain refinement which might be described as settling into place of the molecules while under motion due to the hammering.
3. Improvement of the metal by "working." This effect is well known but of least importance on account of the remelting of the deposit.
4. Fourth, and very important effect, is the cleaning of the surface of slag or dross; and peening should be done so as not to include slag in succeeding layers or flow the metal by heavy or too many blows so as to fold over itself to cause faults.

The cleaning of welds for subsequent layers is absolutely necessary but it has not always been so realized. Of course, in addition to peening and caulking there is sand blasting and other mechanical means of cleaning but probably the most popular is the chemically fluxed electrode which leaves only such dross that a hand or motor-driven brush can remove.

To summarize the valuable uses of peening:

1. Stress-relief by helping the molecules to settle in their ultimate position due apparently to the rattling action.
2. The flowing of the metal in a direction opposite to the contraction strains of the weld.
3. Working of the metal of the weld deposit.
4. Cleaning of the weld surface and smoothing it into shape for perfect subsequent layer deposits.
5. Bringing the welding pieces back into the exact dimensions (even to one thousandth of an inch) as is described in the rest of this chapter.

A separate but even greater use of peening or caulking is its use as applied to heavy section repairs. The specialist must,therefore, apply himself in order to remain up-to-date. The electric arc method is generally selected primarily because of its flexibility and practically unlimited application and economy. The particular purpose here is to call attention to what can honestly be called precision welding. When we say "precision," we mean precisely that, not almost correct, but within two thousandths of an inch. It was not so long ago that even the machining of a large crank shaft to two thousandths of an inch tolerance was not an easy problem, especially when its assembled or complete weight was between five and seventy-five tons. Today, however, this is the standard tolerance and is lived up to by reliable engine manufacturers.

It is now possible, through the use of precision instruments that are capable of measuring the alignment of a shaft that is assembled in an engine frame and the electric arc process with peening, to repair or straighten a broken or twisted shaft or a broken casting to the same degree of strength and accuracy as that given it by the manufacturer.

Not only can this be reached but errors in design can be corrected by welding. It can readily be understood that we cannot line up a piece of machinery any closer than its machined surface but the precision obtainable by the use of electric arc welding is practically infinite, there being no practical instrument capable of measuring the fineness of deflection obtainable through the use of electric arc. We can, to a considerable degree, correct machining faults in large machined pieces, even after considerable use and when age, with its normalizing influence, has caused a warpage or springing of the crank shaft, due to original tolerance at a very small cost of labor. When we say equal to the original tolerance, we do not mean in one particular measurement, but in all of them,

of which there are many on a multiple throw shaft. Its warped condition, after use and age, is produced by the natural tendency of the original forging strains to neutralize or equal one another. As a result, a shaft that might have been machined to a tolerance of one thousandth of an inch may, in the course of time, even though it be kept in storage, incur a warpage of ten to fifteen thousandths.

The classes of work coming under the head of precision jobs not only include crank shafts of steel but cast iron or cast steel as well and the term can be employed wherever a large mass of steel requires bending, straightening or twisting. The crank shaft may become twisted in various ways. It may be that the flywheel of an engine is suddenly stopped. The inertia is liable to twist the section between the flywheel and the crankthrow or counterbalance weights, or in another instance, the cylinder may, during the course of starting or stopping the engine, come up against a water head, and in that case the inertia of the flywheel would produce a tendency to twist the shaft. In multiple throw engines, we have on record cases of broken connecting rods or piston rods that caused sudden stopping of one particular throw and the momentum of the balance of the moving parts produced twisting in one or more places. This twisted condition can also be overcome by the electric arc, within certain limits, of course.

Suppose a high-pressure cast-iron cylinder should have its whole flange broken off completely around the cylinder, due to a broken or loosened piston rod or water head. Although a delicate problem, it is a practical undertaking to replace this flange on all cylinders over two feet in diameter and also to have all of its gaskets face tolerance equal to the original. In undertaking work of this nature, a complete practical knowledge and understanding of expansion and contraction of metals is necessary. A technical knowledge is desirable but not a necessity. The operator or supervisor must thoroughly understand the use of precision instruments, some of which he must be capable ot devising himself to suit the individual problem confronting him. The electric arc method is the only method that can be employed to a satisfactory degree and should be a direct current welding circuit. Low voltage is preferable due to its limiting the possibility of burned or porous metal caused by the long arc. The welding current should not exceed 150 amperes and should be well regulated so that it can be held constant at all times, regardless of the variations of the arc length due to the human element. Such control of the current means that, regardless of the area of the weld or puddle of molten metal under the arc, the heat per unit area of this puddle will be constant.

The fracture, whether it lays directly in the crank pin, main shaft or web of a shaft, should be chipped off from the opposite sides, where possible. In a round section, it should be chipped to a point, leaving a V of approximately 90 deg. between the two pieces when they are assembled. The metal should be thoroughly clean and free from carbon pockets or shrinkage cracks before attempting to weld. The two parts are then placed together with the points of the V or chipped section in line with each other and with an opening between them of $^1/_8$ in. or more, so that complete fusion of the added metal with either side of the V may be obtained.

The next step to be taken is the alignment of the work which, without question, is the most difficult problem encountered in the whole repair. Provision must be made in the original alignment for shrinkage of the metal in the primary weld taking the two pieces together. When this alignment has been completed and the connecting weld is made, check measurements should be taken from all angles. It is often found that the shrinkage of the tacking weld is greater or less than anticipated and, within reasonable limits, such errors can be corrected by the use of a peen hammer to effect an expansion, or, if contraction is required not exceeding three or four thousandths of an inch, the application of one additional layer may give the desired results. In no case should a contraction be allowed to remain in more than two layers of the original connecting weld. When the error in alignment exceeds three or four thousandths in either direction, good practice makes it necessary to chip out or break through this original weld and then start over again. The operator may have to repeat this operation many times before an absolute zero point is obtained. When this has been accomplished, the difficult part of the job is past.

The process from then on consists solely in the repeated application of single layers of metal on all sides of the weld. If desired, each layer may extend over the whole fractured surface. Shrinkage strains, which will be set up in each layer, are removed by the use of a peening tool. Additional metal must not be applied at any time until all shrinkage of the metal already deposited has been relieved, so that all indicators reach zero. It is advisable during the application of a layer, to occasionally watch the indicators to acquaint oneself with the location and the amount of the actual stresses. By continued observation of the micrometers along the welding, a perfect understanding of contraction can be obtained. This same observation is advisable during the peening process so that the operator may familiarize himself with the actual amount of peening required to effect a neutral weld. The understanding of contraction and expansion, as above outlined, will, in the course of a short time, enable the operator to estimate very closely the amount of peening necessary on work where the use of precision instruments is not practical and should prove a very valuable asset to any operator.

The extent of contraction varies considerably and usually is in direct proportion to the variation in carbon in the electrode metal. As is readily understood, contraction stresses set up by a hard, high carbon metal will produce more of a deflection or shrinkage than those of a soft metal, and the hard metal also requires an additional amount of peening to accomplish the neutralization. Any deflection sideways in the welding of the crank shaft may also be corrected by peening. It is absolutely essential that no more than one layer be applied over the entire surface of any precision weld before peening. It is definitely proved that the expansion produced by the miniature forging blows of a pneumatic hammer do not forge the metal any deeper than $^1/_4$ in.

The expansion of a second layer on top of a layer, that has been applied without peening, will merely create additional tensile stress severe enough to probably cause an invisible fracture in the underlying layer. There are also times when, due to the thickness of a layer, along with its hardness from the use of a particularly hard metal, the contraction stresses cannot be relieved until continued peening has flaked off a certain amount of this surface of the weld. It is a fact that when a thin layer of white hot metal is homogeneously applied to colder metal, it sets up tremendous strains and when applied with a thorough knowledge, can be used to accomplish desired distortions in large steel sections that cannot be obtained in any other manner. It is also acknowledged that this thin layer of metal, which has tied up in itself thousands of pounds of pull created by contraction, can readily be normalized or expanded to a normal condition by the means of the forging effect of a peening hammer. Layer upon layer may be applied and treated with micrometers

or indicators as gages with absolute confidence, so that, if carefully and accurately done, the finished mass of metal will absolutely be normal or neutral with neither expansion or contraction stresses, thus doing away with the necessity for annealing.

There is also good reason to believe that the forging effect of a hammer increases ductility and tensile strength of the metal in the same manner as the forging of steel. The full value of the peening process might be compared very favorably with the steel forging, inasmuch that it flattens out the individual grains of metal and produces amalgamation between these grains, that is lacking in the original weld. It is definitely known that a grain of pure steel is surrounded by a shell of impurities. In the event of a fracture, it will follow the line of impurities between each grain and does not have to break through the center, which is the pure steel. By peening or forging, this grain is so flattened that it takes on an overlapping layer effect and the fracture has to make its way through layer after layer of pure steel.

Not only does the peening produce an increased strength, but it makes possible a neutral weld and also the process of obtaining precision welding.

When it comes to cast-iron welding, the welding world, as a whole, is more or less under the impression that studding of the welded areas is absolutely essential as a safety factor. In reality, where studs are applied without the peening process, they merely help to strengthen a faulty weld. We do not disapprove of studding as we have determined that it is an advantage even when employed in a neutralized or peened weld, inasmuch as it anchors the contraction of the original bounding layer and permits a greater area of metal to be welded before peening, without danger of contraction becoming great enough to effect a fracture through the thin layer of chilled cast iron directly under the juncture line. We have, in a number of cases where we have had ample time to complete a job, welded cast iron entirely without studs, but when this process is followed, it is necessary to peen every square inch of the metal as it is applied. If this is not done, the strains set up parallel with the weld will be great enough to fracture at the puncture line. We have proved through numerous tests that the section which usually cracks directly under the chilled area is of higher tensile strength than the actual cast iron itself, but the shearing strains set up at this point, due to the tremendous amount of contracting, are great enough to produce a fracture, even though it had a tensile strength of three or four times the original casting. In cases where we have followed out the peening theory of one inch at a time, we have accomplished very successful welds without the use of studs, having a parting strength greater than the iron itself.

In making the above statements, it is naturally assumed that the correct welding material is used and on cast iron; there is no one or two welding wires that will satisfactorily fuse with every piece of cast iron. We might also add that the welding rod is, without question, a very important item and should be given as much consideration as the operator or the machine. In fact, successful welding may be divided into three parts of very nearly equal importance: the operator, the machine and the wire. Very often it is found that with the very best of equipment welding results are not satisfactory due to the use of an inferior welding electrode. In another instance, the electrode and material may be of first-class quality and the operator is not of the interested and progressive type.

In stock today are carried possibly six or seven different grades of wire for use on cast iron and it is usually possible to find one among this assortment that successfully gives a perfect fusion with cast iron. Castings that are older than 20 years have been found in several cases to contain a considerable excess of phosphorus or sulphur. At times, it requires considerable experimenting to produce a counteracting chemical to overcome the detrimental effects of an excess of phosphorus or sulphur.

When one stops and really figures out the tremendous shrinkage strains set up in a cast-iron weld having a cross section of five inches or more and it is realized that most such welds have been made without provision for relieving the strains, one is not surprised that the welding of cast iron has not generally met with commercial success.

No longer need haphazard methods nor imperfect welds be tolerated. It is now possible to surround any emergency with a cooperative effort based on many years of actual welding and engineering experience. An enormous variety of undertakings have been encountered and mastered under every condition that could be conceived.

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(*Continued from page 3*)

Lukenweld Elects Chapman Vice-President

Everett Chapman, who joined Lukenweld, Inc., division of Lukens Steel Company, Coatesville, Pa., early in 1930 as Director of Engineering and Research, has been elected Vice-President. Lukenweld, Inc. is engaged in the design and manufacture of welded steel assemblies for machinery and equipment.

After graduation in 1924 from the University of Michigan, with a Master's degree in physics, Mr. Chapman taught electrical engineering at Purdue University, leaving to serve the Lincoln Electric Company of Cleveland, on experimental research and development.

Since joining Lukenweld, Inc., Mr. Chapman has been credited with responsibility for that organization's engineering achievements in the application of welded steel construction to Diesel engines, presses, planers, lathes, and other machinery and equipment. Members of the Society wish Mr. Chapman success in his new position.

Welding Handbook Reissued in Enlarged Form by Lincoln

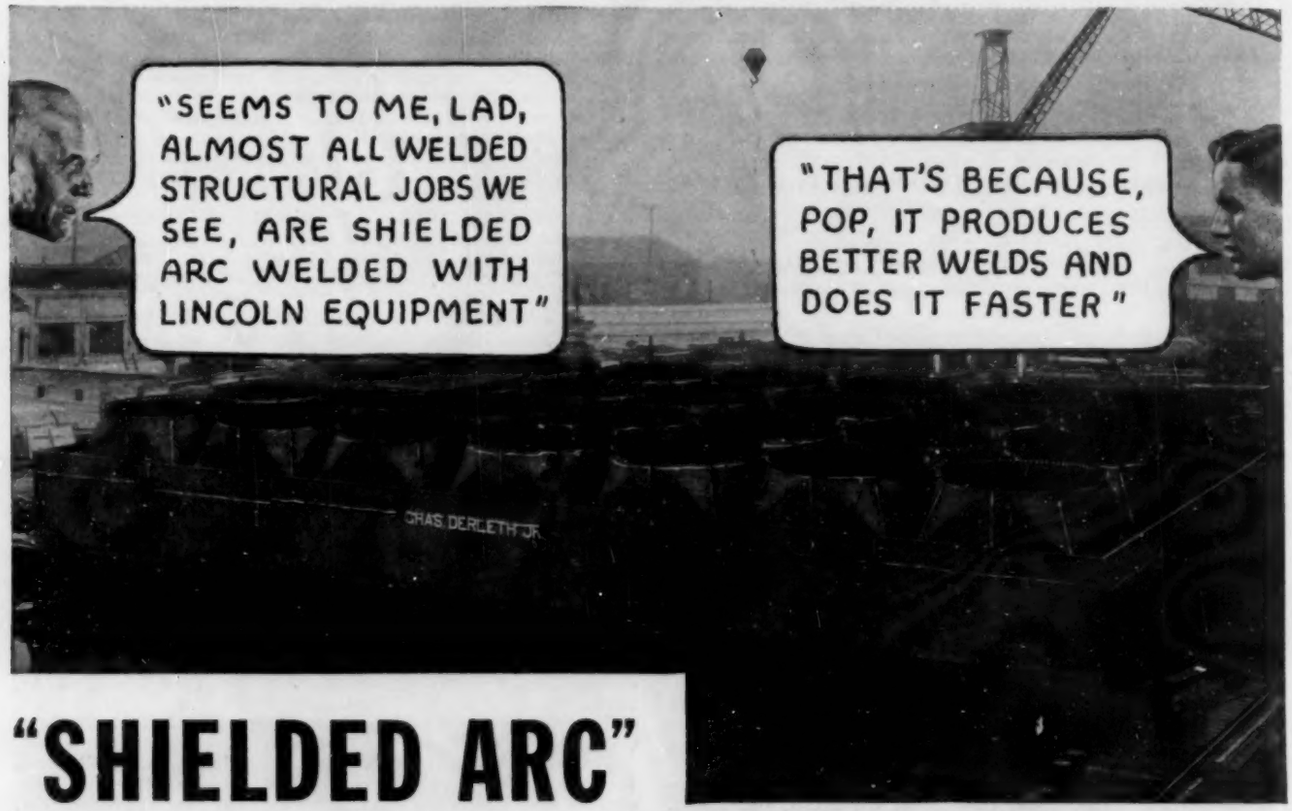
A revised and enlarged edition of "Procedure Handbook of Arc Welding Design and Practice" is announced by The Lincoln Electric Company, Cleveland, Ohio. The book has been reissued because of the demand which exhausted the original issue published last Fall.

The new volume is greatly enlarged in scope and contents. It contains over 450 pages with several hundred illustrations. The eight principal sections deal with various phases of arc welding in a simple, concise manner, well illustrated with detailed drawings and photographs. Taken together, they cover practically every use and application of arc welding.

Among the many additional features which have been included in the new edition are the following: weld inspection (visual, stethoscopic, electro-magnetic, X-ray and Gamma ray); study of stress distribution by means of polarized light; a simplified method for the design of arc-welded machinery; procedure and speeds for arc welding aluminum; technique and speeds for welding of copper; conconstruction of welded water lines, etc.

Change in Filler Metal Specifications

Attention is called to the fact that in the tentative Specifications for Filler Metal Bulletin No. 2 of the AMERICAN WELDING SOCIETY revised June 1, 1933, A. S. T. M. Specification A-140 is called for as base metal to be used for conducting the tests. This specification has been replaced by A7-33T Building Steel and A9-33T Mild Steel Plate.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More than 400,000 lineal feet of welds, produced by the shielded arc process with Lincoln "Fleetweld" electrodes, are contained in the seven caisson cutting edges recently completed for the piers of the San Francisco-Oakland bridge. By using Lincoln "Fleetweld" electrodes the builders of these caisson cutting edges were able to more than satisfy the minimum requirements of 65,000 lbs. per sq. in. tensile strength and ductility of 18% elongation in two inches, for all welds made in flat, vertical or overhead positions.

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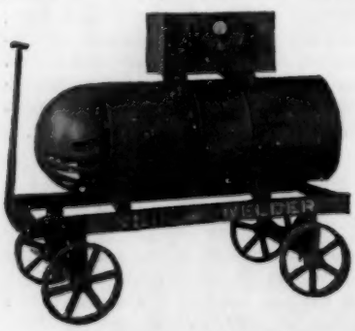

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